

THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 23

JANUARY, 1938

No. 1

A STRUCTURAL INVESTIGATION OF THE ISOMORPHISM OF THE APATITE GROUP

DUNCAN McCONNELL,

University of Minnesota, Minneapolis, Minnesota.

INTRODUCTION

A mineral name has never been more appropriately selected than that of apatite, which is from ἀπατάω (I deceive). Nor has this deception been limited to elementary students: indeed, the variability of the properties and modes of occurrence of the members of the apatite group are so great as to have resulted in the failure to refer certain of them to the apatite group even since the beginning of the twentieth century. In other studies the manner of substitution of some of the ions, commonly present, has been poorly understood or wholly misunderstood.

This study cannot hope to treat the subject exhaustively, because there are not sufficient data available to do so. The optical properties of these minerals will not be considered in the present work, except as they may have a bearing upon the identification of the materials studied. The optical properties have been discussed in some detail by Hausen (1) who also gives an extensive bibliography to 1929. The identification of the several members of the apatite group on the basis of their refractive indices is probably fully as unreliable as the determination of the various garnets by this means. The properties reported for various synthetic apatites are not consistent, and several of these also are inconsistent with the data on natural materials.

Some new chemical data have been obtained, however, and more than thirty x-ray powder diagrams have been examined. The more important of these were measured and the dimensions of the unit cells have been determined and compared with one another and with fluor-apatite. This has led to several entirely new conclusions concerning the isomorphism of the group and has verified some of the ideas previously held. This is also a justifiable basis on which to assume that certain substances bearing different names are identical, and an attempt is made to remove some of the confusion regarding the nomenclature of these minerals.

There are many analyses of the various members of the apatite group on record, but most of these antedate the more reliable methods for the determination of some of the constituents which are reported. The analytical difficulties encountered among these materials are so great as to cast serious doubt upon the reliability of any analyses made prior to 1910, as well as those which were not made by analysts with considerable experience in mineral analysis. The rather arbitrary deduction of supposed "impurities" and the failure to test for all of the probable constituents has greatly added to the difficulties in interpreting some of the analyses.

The apatite group [exclusive of pyromorphite, svabite, mimetite and vanadinite] may contain significant amounts of the following metals: Ca, Mg, Mn, Sr, K and Na. In addition to these a number of analyses report BaO, CrO, FeO, Fe₂O₃, Cr₂O₃, Al₂O₃, et al., but these constituents were not investigated in the present work and it is questionable whether or not these can enter the apatite lattice in significant amounts. Cerium and the rare earths also occur, according to Starynkevič-Borneman (2), but no specimens known to contain these elements were examined by the writer. A number of negative ions and groups may be expected also: PO₄⁻³, AsO₄⁻³, VO₄⁻³, SiO₄⁻⁴, SO₄⁻², CO₃⁻², F⁻, Cl⁻, OH⁻ and O⁻².

The writer is indebted to Dr. J. W. Gruner for his interest in this problem and for numerous valuable suggestions. He is further indebted to Dr. R. B. Ellestad, of the Laboratory for Rock Analysis, for a number of valuable analytical determinations and for helpful suggestions. A number of individuals and institutions have generously contributed the specimens used in this study. The following materials were examined:

Apatite

- I. Fluor-apatite, from Faraday Township, Hastings County, Ontario. Kindly furnished by Mr. A. S. Dadson, Toronto, Ontario. (3)¹
- II. Labelled "Apatite, from Nishiyamanashigun, Kai, Japan." This apparently is not an ordinary fluor-apatite and no reliable analysis is available.
- III. Fluor-apatite, locality unknown.

Francolite

- IV. Labelled "Apatite, var. staffelite, from Staffel on Lahn, Nassau." Purchased from Ward's Natural Science Establishment, Rochester, N. Y. (4)
- V. Labelled "Grod nolite, from Raków, near Grodno, Poland." Kindly furnished by Dr. J. Morozewicz, Director of the Geological Survey of Poland. (5)

Dahllite

- VI. No. 106,181, Museum of Natural History, Paris. Dahllite, from Mouillac, Quercy, France. Kindly furnished by Dr. A. Lacroix. (6)

¹ The numbers following the descriptions of the specimens refer to the bibliography. In many cases a number of descriptions are on record, but usually only the most recent or most complete description is given for reference.

- VII. Dahllite, from near Ishawooa, Wyoming. Kindly furnished by Mrs. F. C. Sayles, Jr., Ishawooa, Wyoming. (7)
- VIII. Dahllite, from near Junction City, Ky. Kindly furnished by Dr. Raymond Edmundson, Cornell University, Ithaca, N. Y. (8)
- IX. Labelled "Podolite, from Podolien, Fluss Uschiza, Zurzewka." Kindly furnished by Dr. V. Chirvinsky, Ukrainian Geol. Research Trust, Kiev, U. S. S. R. (9 and 10)

Dehrnite

- X. No. R5590, U. S. National Museum. Dehrnite (Kalkwavellite), part of type specimen, from Dehrn, Nassau. Kindly furnished by Dr. W. F. Foshag. (11 and 12)
- XI. Labelled "Dehrnite, not analyzed, Utah." Kindly furnished by Dr. E. S. Larsen, Harvard University, Cambridge, Mass. (11 and 12)
- XII. Labelled "Dehrnite, from Utah." Kindly furnished by Dr. F. H. Pough, American Museum of Natural History, New York, N. Y.

Lewistonite

- XIII. Lewistonite, from Utah. Kindly furnished by Dr. F. H. Pough. (12)

Fermorite

- XIV. No. 326, Geological Survey of India. Fermorite, from Sitapar Manganese Mine, Sausar Tehsil, Chhindwara District, Central Provinces, India. Kindly furnished by the Director at the request of Dr. M. S. Krishnan, Calcutta, India. (14)

Ellestadite

- XV. Ellestadite, from Crestmore, Riverside County, California. Kindly furnished by Dr. Adolf Pabst, University of California, Berkeley, California. (15)

Wilkeite

- XVI. Wilkeite, from Crestmore, Calif. Purchased from Mr. R. M. Wilke, Palo Alto, California. (15)
- XVII. Wilkeite, from Crestmore, Calif. Purchased from Ward's Natural Science Establishment, Rochester, N. Y. (15)

Mangan-apatite

- XVIII. No. 86,790, Harvard University Collection. Manganapatite, from Buckfield, Maine. Kindly furnished by Dr. Harry Berman, Cambridge. Mass. (16)

Collophane and various mixtures

- XIX. No. 80,177, Museum of Natural History, Paris. Labelled "Quercyite, Castillo de Belmez, Espagne." Kindly furnished by Dr. A. Lacroix. (17)
- XX. Labelled "Sandy phosphorite, from Kursk" [kurskite]. Kindly furnished by Dr. V. Chirvinsky, Ukrainian Geol. Research Trust, Kiev, U. S. S. R.
- XXI. Podolian phosphorite, Uschiza River, Zurzewka, Podolia. Kindly furnished by Dr. V. Chirvinsky.
- XXII. Labelled "Dahllite, from Ochotnikov, near Kiev, Ukraina." Purchased from Mr. R. M. Wilke, Palo Alto, California.

THE STRUCTURE OF FLUOR-APATITE

In the pages that follow, the isomorphous substitutions have been discussed in terms of the structure of fluor-apatite and, for this reason, it is essential to discuss this structure briefly at this point.

Náray-Szabó (18) and Mehmél (19 and 20) have shown that the structure contains the following ions: 10 Ca, 6 P, 2 F, and 24 O. The positions of these ions are given in Fig. 1, slightly modified according Mehmél (20).

Because these authors have arrived at similar conclusions working independently, it seems almost conclusive that this structure is essentially correct. The calculations of Náray-Szabó have been extremely useful as a check in the present work.

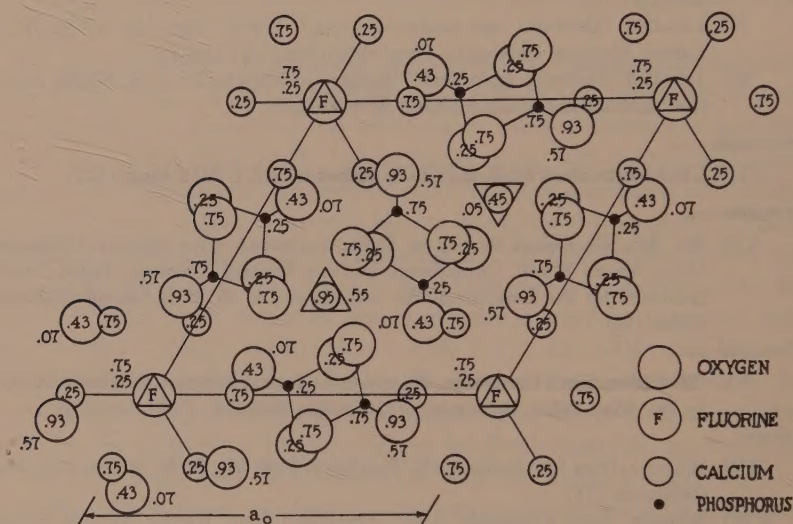


FIG. 1. Projection of the unit cell of fluor-apatite on (0001). The heights of the various ions are indicated as fractions of c_0 .

The interplanar distances for fluor-apatite, from Ontario (specimen I), with unfiltered iron radiation are given in Table 1, column 1. The calculation of the unit cell for this material is comparable with the results of Náray-Szabó and Mehmél, as follows:

	a_0	c_0	c/a	Vol.
fluor-apatite, Ontario, I	$9.36 \pm .01$	$6.88 \pm .01$	.7350	522
fluor-apatite (Náray-Szabó)	$9.37 \pm .01$	$6.88 \pm .01$	.7342	523
fluor-apatite (Mehmél)	$9.36 \pm .02$	$6.85 \pm .02$	.7318	520

If it is assumed that each of these specimens represents pure fluor-apatite and the theoretical densities are calculated on the basis of the molecular weight of the theoretical fluor-apatite (1008.9), the results show only slight differences. The values thus calculated are, respectively:

TABLE 1. COMPARISONS OF POWDER DIAGRAMS OF VARIOUS MINERALS OF THE APATITE GROUP. (Unfiltered Fe Radiation— $\gamma = 57.3$ mm.)

No.	Indices	Fluor-apatite		Francolite		Dahllite		Mangan-apatite		Fermorite		Dehrnite		Lewistonite		Wilkeite	
		<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>
1	111	—	2	—	2	—	2	—	2	3.952	0.5	—	1	—	—	—	—
2	002	3.432	2	3.431	2	3.437	2	3.386	2	3.494	3	3.432	1	3.449	1	3.452	2
3	102	—	—	3.157	0.5	—	—	3.134	0.5	—	—	3.160	0.5	3.169	0.5	—	—
4	120, 210	3.060	3	3.044	2	3.077	3	3.050	2	3.143	1	3.044	3	3.068	2	3.109	3
5	300 β	2.975	0.5	2.957	0.5	2.990	1	2.967	0.5	3.052	0.5	2.960	0.5	2.982	0.5	3.026	0.5
6	202 β	2.884	0.5	2.844	0.5	—	—	—	—	—	—	—	—	—	—	—	—
7	121, 211	2.798	>10	2.765	>10	2.811	>10	2.784	10	2.866	>10	2.765	>10	2.798	>10	2.830	>10
8	112	2.769	4	2.769	4	2.778	3	2.750	3	2.824	5	2.765	6	2.771	4	2.795	4
9	300	2.702	6	2.683	7	2.712	6	2.694	8	2.769	8	2.685	6	2.700	6	2.731	6
10	202	2.616	3	2.618	4	2.628	1	2.599	4	2.675	2	2.613	3	2.622	2	2.642	3
11	301	2.517	0.5	2.508	0.5	2.524	0.5	—	—	—	—	2.507	0.5	—	—	—	—
12	130 β	2.477	0.5	2.462	0.5	2.493	0.5	—	—	—	—	2.462	0.5	—	—	—	—
13	122, 212	2.289	0.5	2.277	1	—	—	—	—	—	—	2.281	0.5	—	—	—	—
14	130, 310	2.248	2	2.238	3	2.256	4	2.240	6	2.306	1	2.234	4	2.247	2	2.276	3
15	131, 311	2.135	1	2.127	2	2.145	2	2.128	2	2.191	1	2.124	2	2.134	1	2.157	1
16	222 β	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	113	2.057	1	2.060	1	—	—	2.042	0.5	—	—	2.054	0.5	2.058	0.5	—	—
18	123 β	2.026	0.5	2.020	1	2.031	0.5	2.012	0.5	2.063	1	2.020	0.5	2.020	0.5	2.030	0.5
19	203	2.001	0.5	1.996	1	—	—	1.977	0.5	—	—	—	—	—	—	2.007	0.5
20	231 β	—	—	1.967	0.5	1.993	0.5	—	—	2.031	0.5	—	—	—	—	—	—
21	222	1.937	3	1.928	3	1.941	4	1.925	6	1.980	5	1.926	6	1.934	3	1.956	4
22	132, 312	1.883	1	1.876	1	1.888	1	1.872	3	1.926	1	1.877	2	1.880	1	1.902	1
23	123, 213	1.838	6	1.835	3	1.840	2	1.820	8	1.873	8	1.831	6	1.833	5	1.849	4
24	231, 321	1.795	3	1.788	2	1.805	2	1.790	3	1.840	2	1.789	2	1.795	2	1.818	1
25	140, 410	1.769	3	1.762	2	1.778	1	1.764	3	1.814	2	1.759	2	1.768	2	1.792	1
26	402	1.745	3	1.740	2	1.753	1	1.738	3	1.788	2	1.742	2	1.745	2	1.766	1
27	004	1.720	3	1.720	2	1.721	1	1.703	3	1.749	3	1.719	2	1.721	2	1.727	2
28	232, 322	1.637	1	1.631	0.5	1.645	0.5	1.629	2	1.675	1	1.631	1	1.635	1	1.655	0.5
29	133, 313	1.605	0.5	1.601	0.5	—	—	—	—	1.641	0.5	—	—	—	—	—	—
30	240, 420	1.533	0.5	1.525	0.5	1.538	1	1.531	1	1.574	0.5	1.527	0.5	—	—	—	—
31	331	1.521	0.5	1.515	0.5	1.502	1	1.517	1	1.560	0.5	1.516	0.5	—	—	1.511	0.5
32	124, 214	1.498	1	1.496	0.5	—	—	1.488	1	1.531	1	—	—	—	—	1.486	1
33	502	1.468	2	1.462	1	1.473	1	1.462	2	1.504	1	1.464	2	1.466	1	1.467	1
34	304	1.452	1	1.453	1	1.455	1	1.439	2	1.478	2	—	—	—	—	—	—
35	233, 323	1.445	1	1.441	1	—	—	—	—	—	—	—	—	—	—	—	—
36	151, 511	1.424	1	1.419	1	1.434	2	1.421	3	1.462	1	—	—	—	—	1.439	0.5

3.187, 3.180 and 3.201. Actually, the differences are probably due to differences in the chemical compositions of the apatites examined, but, because the theoretical density is one of the fundamental considerations in several instances below, this uniformity of results is emphasized here.

In the sections to follow, the isomorphism is discussed under the headings of substitutions for: (1) calcium, (2) phosphorus, (3) fluorine and (4) oxygen.

TABLE 2. CHEMICAL ANALYSES OF VARIOUS MINERALS OF THE APATITE GROUP

	1	2	3	4	5	6	7	8	9
CaO	55.16	51.02	53.65	47.33	44.34	50.88	46.78	54.88	55.47
MgO		0.47						0.31	
MnO	0.12			8.67					0.06
SrO					9.93				
Na ₂ O		0.7				7.11	4.34		
K ₂ O		0.57				1.20	1.36		
CO ₂	0.50	5.79	5.30			1.49		3.36	
P ₂ O ₅	41.30	33.01	38.40	41.43	20.11	37.12	37.92	37.71	42.19
SiO ₂		trace							
SO ₃		1.77						none	
Al ₂ O ₃	0.24	0.20	0.57	0.55		trace	2.53		
Fe ₂ O ₃	0.63	0.66							
F	3.67	3.55	trace	3.80	0.83	none		4.11	
Cl	0.09	trace				none		none	
H ₂ O+	0.01	3.16	2.10	0.06	trace	1.52	7.69	1.14	1.73
H ₂ O-		0.54				0.16		0.04	0.00
Others	0.42	0.77			25.31	0.12		0.24	0.60
Less O	102.14	102.22	100.02	101.84	100.52	99.60	100.62	101.79	100.05
	1.56	1.49		1.60	0.35			1.73	
	100.58	100.73	100.02	100.24	100.17	99.60	100.62	100.06	100.05

1—Fluor-apatite, Faraday Township, Hastings Co., Ontario. A. S. Dadson, analyst. Others=0.14 FeO+0.28 insol.

2—Francolite [grodnotite], near Grodno, Poland. W. Wawryk, analyst. Others=0.47 organic C+0.30 insol. [Possibly the value for Na₂O should be 0.71 (instead of 0.7), in which case the sum would be correct as given.]

3—Dahllite, Mouillac, Quercy, France. F. Pisani, analyst.

4—Mangan-apatite, Buckfield, Maine. H. E. Vassar, analyst.

5—Fermorite, Sausar Tehsil, India. G. T. Prior, analyst. Others=25.23 As₂O₅+0.08 insol.

6—Dehrnite, Dehrn, Nassau. E. V. Shannon, analyst. Others=0.12 insol.

7—Lewistonite, near Fairfield, Utah. F. A. Gonyer, analyst.

8—Francolite [staffelite], Staffel on Lahn, Nassau, Germany. R. B. Ellestad, analyst. Others=0.24 V₂O₅.

9—Hydroxy-apatite, Kemmlen, near Hospenthal. J. Jakob, analyst. Others=0.60 insol

SUBSTITUTIONS FOR CALCIUM FRANCOLITE AND DAHLITE

Some of the substitutions for calcium have been surmised for many years, such as the substitution of small amounts of magnesium, manganese and strontium. The substitution of carbon for calcium is rather surprising, however. Apparently this type of substitution takes place to a limited extent in all carbonate-apatites, but it has been definitely shown only in ellestadite (15) and francolite (4). By analogy C-ions also substitute for Ca in dahllite, dehrnite and lewistonite and, possibly, in merrillite.

The demonstration of the substitution of carbon for calcium requires a rather detailed discussion of the analysis give in Table 2, column 8, and, because Gruner and McConnell (4) have considered these data in considerable detail, their results will receive only brief mention here.

It was found that CO₃-groups could not occur in the positions to which they had been previously assigned for several reasons:

(1) The CO₃-group, being much larger than the F-ion, would require that the size of the unit cell of francolite be larger than that of fluor-apatite. On the contrary it was found to be slightly smaller.

(2) The theoretical density of a carbonate-apatite in which CO₃-groups substitute for fluorine is greater than the density of fluor-apatite but the calculation of the theoretical density of francolite (specimen IV) gives the following:

$$\frac{993.19 \times 1.649}{519.77} = 3.151$$

and this is considerably less than the density of fluor-apatite (3.18). The theoretical density is in excellent accord, however, with an experimental value, which is 3.147 (4°C.).

(3) If CO₃-groups were assumed to occupy F-positions the F-ions would have to occupy other positions in the structure; because there is an excess of fluorine above the amount of the theoretical fluor-apatite; and, furthermore, it would not be possible to reconcile the analysis with the proportion Ca:P:10:6. A statistical distribution of the carbon ions between the P-positions and the Ca-positions was accepted as the most probable explanation. The distribution was found to be as follows:

$$\begin{array}{l} 10 \text{ Ca} = 9.810 \text{ Ca} + .077 \text{ Mg} + .113 \text{ C} \\ 6 \text{ P} = 5.322 \text{ P} + .026 \text{ V} + .652 \text{ C} \\ 2 \text{ F} = 2.000 \text{ F} \\ 24 \text{ O} = 23.732 \text{ O} + .100 \text{ OH} + .168 \text{ F} \\ 42 \quad = \text{number of ionic positions of fluor-apatite} \end{array}$$

This distribution indicates that C-ions replace Ca-ions, but this can take place only in those Ca-positions which are located on three-fold axes (Fig. 1). Figure 2 is an illustration of the supposed manner of this substitution. If this represents a true picture of the manner of introduction of carbon into the structure—and there is every indication that it is the correct one—nitrogen might be expected to enter the structure in the same way if it were available in the proper state of oxidation. The fact that a nitrate-apatite is not known does not weaken the hypothesis, because NO_3 -groups are probably not available in the environment in which most of these minerals form and, in most cases, there has probably not been an attempt to ascertain the presence or absence of NO_3 -groups by analysis.

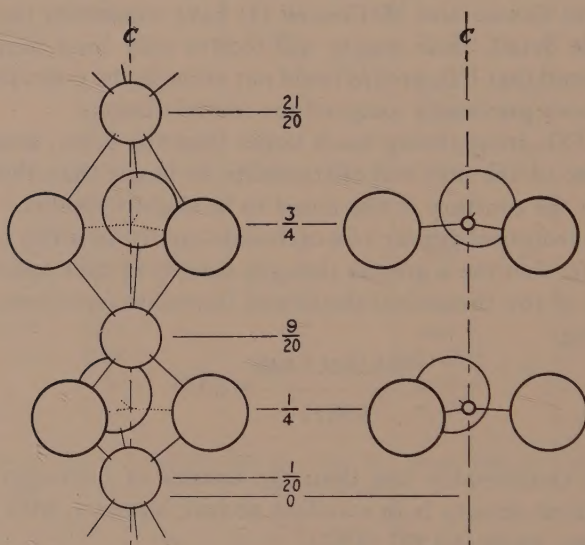


FIG. 2. Clinographic projection of the ions immediately adjacent to the three-fold axes on which the Ca-ions are located, showing the hypothetical manner of the displacement of Ca-ions by C-ions with the formation of CO_3 -groups. The circles represent oxygen, calcium and carbon in order of decreasing sizes.

Two specimens of francolite were examined and they compare with each other, and with fluor-apatite as follows:

	a_0	c_0	c/a	Vol.
fluor-apatite, I	$9.36 \pm .01$	$6.88 \pm .01$	.7350	522
francolite, IV	$9.34 \pm .01$	$6.88 \pm .01$	.7366	520
francolite, V	$9.32 \pm .01$	$6.88 \pm .01$	.7382	518

The interplanar distances for francolite [grodnolite] are given in Table 1, column 2. Although a chemical analysis of this material has

been recently reported by Tokarski (5) it seems highly improbable that the results are representative of the phosphate mineral which is the chief constituent of a rather complex sedimentary rock. For this reason it seems inadvisable to base calculations upon this analysis, but it is noteworthy that 3.55 per cent fluorine was found (Table 2, column 2). The interplanar distances for francolite [staffelite] have been given (4).

Francolite is a suitable name for an apatite which contains an appreciable amount of CO_2 but which also contains more than one per cent of fluorine. It may or may not contain OH -ions, depending upon the various amounts of other ions present. Francolite should include both a carbonate-fluor-apatite and a carbonate-hydroxy-fluor-apatite (where $\text{F} > 1\%$). Grodnolite is identical with francolite, as shown by Tokarski (5) and confirmed in this work. Staffelite is also identical as has been previously indicated by numerous authors.²

The essential difference between dahllite and francolite is the presence of appreciable amounts of fluorine in the latter compound and the absence of appreciable amounts in the former. Dahllite, as it is here defined contains less than one per cent of fluorine, but this limit is arbitrary and probably of no structural significance. It is noticeable however, that most apatite analyses indicate considerably less than one per cent of fluorine or considerably more than this amount. Dahllite is a carbonate-hydroxy-apatite.

Dahllite from Quercy has been analyzed by Pisani (6, p. 1390) with the results shown in Table 2, column 3. The CO_2 -content of specimen VI was determined as 4.35% by Dr. R. B. Ellestad and the fluorine was found to be 0.19% by Dr. W. D. Armstrong, so it may be concluded that this material is essentially similar to the dahllite from the same locality which Pisani analyzed. The interplanar distances obtained for this material are given in Table 1, column 3.

The dimensions of the unit cells of several dahllite specimens are comparable with fluor-apatite and with each other as follows:

² Since going to press a personal communication has been received from Mr. M. H. Hey, of the British Museum, and it states in part: "I . . . do not agree that Schaller's conclusion [regarding the identity of staffelite and francolite (*U. S. Geol. Surv., Bull.* 509, pp. 89-95, 1912)] is proven—only that it is probable. The name francolite undoubtedly belongs to the material collected from the mine Wheal Franco, Buckland Monachorum, Traristock, Devon, and nobody knows just what this material is."

Mr. Hey kindly called attention also to the fact that neither the material analyzed by Henry (*Phil. Mag.*, vol. 36, p. 134, 1850) nor the material analyzed by Maskelyne and Flight (*Jour. Chem. Soc.*, vol. 24, p. 3, 1871) was from the Wheal Franco mine.

Under these circumstances a definite choice between the names francolite and staffelite cannot be made until the material from the Wheal Franco mine has been analyzed. Mr. Hey has indicated that microchemical methods would be required.

	a_0	c_0	c/a	Vol.
fluor-apatite, I	$9.36 \pm .01$	$6.88 \pm .01$	.7350	522
dahllite, Quercy, VI	$9.41 \pm .01$	$6.88 \pm .01$	.7311	528
dahllite, Wyoming, VII	$9.39 \pm .01$	$6.88 \pm .01$	.7329	525
dahllite [podolite], IX	$9.41 \pm .01$	$6.89 \pm .01$	.7322	528

It seems reasonable to assume in the case of specimen VI, that carbon replaces both calcium and phosphorus because this was the condition encountered in francolite (specimen IV), but there is need of further theoretical justification for the substitution of carbon for calcium in view of the fact that only a small amount of carbon has been shown to substitute for calcium in this compound.

This justification seems evident in the case of the alkali-apatites (dehrnite and lewistonite), because here an excess of negative charges would occur if substitution of OH-groups for O-ions did not tend to decrease the negative charges. As CO_2 is also present in these compounds it becomes necessary to assume that the carbon substitutes for calcium rather than phosphorus as the former substitution would also decrease the number of negative charges, whereas substitution of carbon for phosphorus would increase the negative charges. The analyses of these materials which are available hardly show sufficient water to produce electrostatic neutrality if carbon substitutes for calcium, and the substitution of carbon for phosphorus would require a considerably greater number of hydroxyl ions to produce electrostatic neutrality.

A more detailed investigation of the composition of dahllite seems necessary to establish conclusively that there is a significant amount of calcium replaced by carbon and this investigation is now in progress.

FERMORITE AND MANGAN-APATITE

During the time this work was in progress only one specimen of mangan-apatite was available. This specimen (XVIII) is probably quite similar to the material studied by Landes (16) and analyzed by H. E. Vassar (Table 2, column 4). Dr. S. S. Goldich kindly determined the manganese content of this material. Based upon his manganese determination alone, the following composition has been assumed for the purpose of calculations:

	Computed wt. of oxides	No. of ions	M. W.
CaO	46.3	Ca = 8.50	340.6
MnO	$10.3 \pm .2$	Mn = 1.50	82.4
P ₂ O ₅	41.3	P = 6	186.2
F	3.7	F = 2	38.0
	<u>101.6</u>	<u>O = 24</u>	<u>384.0</u>
Less O	1.6	42	1,031.2
	<u>100.0</u>		

If the molecular weight is taken as 1031, the theoretical density becomes 3.317 for the lattice dimensions given below. This is comparable with the measured density which is 3.301 (4°C.). The density of mangan-apatite is appreciably greater than that of the ordinary fluor-apatite because the lattice dimensions are smaller and the molecular weight is greater. The lattice dimensions are comparable with fluor-apatite as follows:

	a_0	c_0	c/a	Vol.
fluor-apatite, I	$9.36 \pm .01$	$6.88 \pm .01$	.7350	522
mangan-apatite, XVIII	$9.33 \pm .01$	$6.80 \pm .01$	.7288	513

Fermorite is an example of the substitution of Sr for Ca but this mineral also shows an appreciable substitution of As for P. Specimen XIV has the largest unit cell observed for any of the materials examined, and it compares with fluor-apatite as follows:

	a_0	c_0	c/a	Vol.
fluor-apatite, I	$9.36 \pm .01$	$6.88 \pm .01$	.7350	522
fermorite, XIV	$9.60 \pm .01$	$7.00 \pm .01$	.7292	559

The interplanar distances for fermorite from Sausar Tehsil, India, are given in Table 1, column 5.

The original analysis (Table 2, column 5) cannot be entirely reconciled with the structure of fluor-apatite, as it is now understood, because the constituents of the F-positions have not been accounted for in a satisfactory manner. For this reason the theoretical density has not been calculated.

DEHRNITE, LEWISTONITE AND MERRILLITE

The powder diagrams indicate that dehrnite is a member of the apatite group, and, although it was not referred to this group in the original description (11), Larsen and Shannon state in a later paper (12) that it may be a member of the apatite group. Their supposition has been confirmed, and the lattice dimensions are as follows:

	a_0	c_0	c/a	Vol.
fluor-apatite, I	$9.36 \pm .01$	$6.88 \pm .01$	.7350	522
dehrnite, X	$9.31 \pm .01$	$6.87 \pm .01$	.7379	516
dehrnite, XI	$9.34 \pm .01$	$6.89 \pm .01$	.7377	521
dehrnite, XII	$9.35 \pm .01$	$6.89 \pm .01$	.7369	522

The interplanar distances obtained for the specimen from Dehrn, Nassau (X) are given in Table 1, column 6. An analysis by Shannon is shown in Table 2, column 6.

If Na-ions take the place of some Ca-ions of ordinary fluor-apatite, there is an appreciable decrease in positive charges in the structure which

must be taken into account. This is probably accomplished by the substitution of monovalent negative ions for oxygen or the substitution of carbon for calcium, resulting in addition of positive charges. However, this structure has not been given detailed consideration because more accurate chemical data would be required for this work, and a suitable specimen was not available. This type of substitution is considered further below.

The name dehrnite is considered proper for an apatite containing a significant amount of sodium replacing calcium, and also containing CO_2 , a sodium carbonate-hydroxyl-apatite.

The specimen of lewistonite examined in this work indicates that this mineral is also a member of the apatite group, although this view has not been previously advanced. The physical and optical properties of lewistonite are quite similar to those of apatite, according to Larsen and Shannon (12), except the lewistonite is considered biaxial with $2V=42^\circ$. Another specimen (an amygdule) is described as uniaxial and negative (12).

This specimen gave the following dimensions for the unit cell:

	a_0	c_0	c/a	Vol.
fluor-apatite, I	$9.36 \pm .01$	$6.88 \pm .01$	.7350	522
lewistonite, XIII	$9.35 \pm .01$	$6.89 \pm .01$	.7369	522
"kurskite," XX	$9.33 \pm .01$	$6.89 \pm .01$	.7385	519

These data are based upon the interplanar distances given in Table 1, column 7. Both of the specimens of dehrnite, from Utah, produce diagrams more closely resembling lewistonite than the dehrnite from Dehrn (specimen X). This would suggest that these dehrnites contain a greater amount of K- or OH-ions than the specimen from Dehrn. Shannon's analysis (12, p. 325) indicates that there are greater amounts of both of these ions in the material from Utah. Apparently the Utah material is intermediate between lewistonite and dehrnite. The unit cell of lewistonite is somewhat larger than that of dehrnite as would be expected from a comparison of the radii of K and Na, but the relative abundance of OH-ions in the two compounds is a complicating factor which prevents a direct comparison.

Lewistonite is considered a suitable name for an apatite containing an appreciable amount of potassium, regardless of the presence or absence of CO_2 . Lewistonite is a potassium carbonate hydroxyl-apatite or a potassium-hydroxyl-apatite.³

³ Hintze's *Handbuch der Mineralogie*, V. 1, Abt. 4, p. 1036, gives dehrnite and lewistonite as varieties of colophane, but this hardly seems justifiable because both of these substances are distinctly crystalline.

Kurskite (specimen XX) produced a pattern quite similar to lewistonite, with which it is compared above. Apparently kurskite should be more closely associated with lewistonite and dehrnite than francolite, but this supposition would be difficult to confirm because it would seem almost impossible to separate this highly contaminated mineral in sufficient amounts for analytical purposes. A qualitative examination with a direct vision spectroscope, however, showed the presence of very strong Na-lines and weak K-lines.

Merrillite, which has been reported as occurring only in meteorites, was not examined because no specimen was available. However, in view of the rather broad limits of the isomorphism in apatite, and the marked similarity between this mineral and dehrnite [previously mentioned by Larsen and Shannon (11)], there can be little doubt that, if this mineral differs from dehrnite, the difference apparently lies in the absence of CO_2 in merrillite. Merrillite may tentatively be considered as a name applicable to a sodium hydroxyl-apatite.

If the statements regarding these minerals do not seem conclusive it is because the recorded chemical data cannot be reconciled with the x -ray data, and it was not possible to obtain sufficient material to check the recorded analytical results. It is to be remembered, however, that the specimens were obtained from the most reliable sources.

In each case (except "kurskite") only one substance appeared to be present and this substance produced a diffraction pattern with intensities similar to those of fluor-apatite but with slightly different values for θ .

SUBSTITUTIONS FOR PHOSPHORUS ELLESTADITE AND WILKEITE

Before discussing an entirely new type of substitution, it is well to recall two types which have already been mentioned above. In fermorite there is a substitution of As-ions for P-ions, and in francolite a very small amount of vanadium substitutes for phosphorus. This sort of substitution involves no difference in valence and has been recognized for many years. The second type of substitution, carbon for phosphorus, however, involves a difference in valence and has not been previously brought to light in compounds of this sort. Here there is an increase in the negative charges associated with each tetrahedron which has carbon at its center instead of phosphorus, and this increase of negative charges must be compensated by other constituents of the structure.

The case would not be nearly so conclusive if it were not for the substitution of Si-ions for P-ions which occurs in wilkeite and ellestadite (15). Here there is an increase of the negative charges associated with those tetrahedra which have Si-ions at their centers, but the electrostatic

neutrality of the structure is produced by the compensating effect of the substitution of sulfur for phosphorus.

The interplanar distances for wilkeite (XVI) are shown in Table 1, column 8, and those for ellestadite have been given elsewhere (15). The lattice dimensions for these materials compare with fluor-apatite as follows:

	a_0	c_0	c/a	Vol.
fluor-apatite, I	$9.36 \pm .01$	$6.88 \pm .01$	.7350	522
wilkeite, XVII	$9.40 \pm .01$	$6.89 \pm .01$	.7330	527
wilkeite, XVI	$9.48 \pm .01$	$6.91 \pm .01$	.7289	538
ellestadite, XV	$9.53 \pm .01$	$6.91 \pm .01$	.7251	544

The apatite-ellestadite series is the only series of the apatite group (as limited above) showing substitutions for phosphorus in which both end-members are known. With the exception of the fluorapatite-hydroxylapatite series it is the only one in which both end-members are known.

SUBSTITUTIONS FOR FLUORINE

In this investigation it was found that CO_3 -groups do not substitute for fluorine in the apatite structure, but occupy other positions as mentioned above. The CO_3 -groups had been relegated to the F-positions or to positions intermediate between the two F-positions on the three-fold axes, but the occurrence of CO_3 -groups in these positions is not possible, as has been shown by Gruner and McConnell (4).

As early as 1856, Damour (21) recognized that OH-ions replaced fluorine in apatite, but his conclusions were not generally accepted until comparatively recently. As shown above, OH-ions occupy the fluorine positions in a number of minerals. Natural hydroxy-apatite has recently been described by Burri, Jakob, Parker and Strunz (22) and compares with fluor-apatite as follows:

	a_0	c_0	c/a	Vol.
fluor-apatite, Ontario, I	$9.36 \pm .01$	$6.88 \pm .01$	.735	522
hydroxy-apatite, Hospenthal	9.42	6.935	.736	533

The most poorly understood substitution for fluorine is oxygen. In 1912 Rogers (23) set down the formula $\text{Ca}_{10}\text{O}(\text{PO}_4)_6$, assuming that one O-ion replaces two F-ions. If this assumption were correct it would require that the O-ions occupy half of the positions intermediate between two F-positions or half of the F-positions, because the space group C_{6h}^2 requires reflection planes at $\frac{1}{4}$ and $\frac{3}{4}$ c . One of these assumptions would require a most peculiar type of coordination—an O-ion at the center of

a distorted octahedron surrounded by 6 Ca-ions. Either assumption would require vacancies in half of the ionic positions of a particular sort. These conditions are objectionable and have been rejected in this work.

To account for oxy-apatite it is necessary to assume that the formula is $(\text{Ca}, \text{X})_{10} \text{O}_2(\text{PO}_4)_6$ or $\text{Ca}_{10} \text{O}_2[(\text{P}, \text{X})\text{O}_4]_6$. In the former case X represents a trivalent metal or carbon (15) or, possibly, nitrogen. In the latter case X represents a hexavalent ion, such as, sulfur. Sulfur and carbon are both present in ellestadite and other analyses of materials supposedly containing the oxy-apatite molecule report CO_2 . More analytical data are necessary to establish which of these formulas is the correct one because some of the constituents reported in the older analyses were determined prior to the development of reliable methods for these constituents.

The substitution of chlorine for fluorine is well known but was not further investigated in this study. Mehmel (20) has based several calculations on the data supplied by Nacken (24), but it would seem that synthetic chlor-apatite should be investigated further, as his value for the specific gravity (3.17) is not consistent with the values reported for most apatites containing a large amount of chlorine. Nor is it comparable with the results of Hendricks, Jefferson and Mosley (25) who give a calculated value 3.20 and measured value 3.25. Cameron and McCaughey (26) obtained 3.010 for synthetic chlor-apatite.

Pehrman (27) has suggested that miscibility of the fluor-, chlor- and oxy-apatite molecules is not complete. He plotted the analyses available in 1925 on a ternary diagram and obtained an apparent hiatus. Hydroxy-apatite was not included in these computations, however, and other rather broad assumptions were required, such as, the validity of the fluorine determinations. Nevertheless, his conclusions seem plausible in view of the significant difference between the radius of chlorine and the radii of fluorine, oxygen and the OH-group.

SUBSTITUTIONS FOR OXYGEN

Gruner and McConnell (4) have found definite evidence of the substitution of fluorine for oxygen in francolite. The amount of fluorine present exceeds that of the theoretical fluor-apatite by only 0.34 weight per cent, to be sure, but this represents an amount about six times as great as the probable error of the method used to determine the fluorine. This mineral also suggests the substitution of OH-ions for oxygen, because 0.90 weight per cent of water was not removed during twenty-four hours at 300°C . However, this cannot be accepted as absolute evidence of the presence of OH-groups substituting for oxygen. The manner of

liberation of the water in these compounds requires further investigation. Several dehydration curves have been obtained using a vacuum apparatus [a so-called tensi-eudiometer (28)] but a satisfactory interpretation of the dehydration curves has not been obtained.

In dehrnite, lewistonite and merrillite there is a strong indication that monovalent negative groups (OH) substitute for oxygen in order to compensate the substitution of monovalent positive ions (alkalies) for the bivalent positive ions (Ca) of fluor-apatite, and thus produce electrostatic equilibrium. As mentioned above, these structures have not been investigated in an exhaustive manner and substitutions of this sort have not been demonstrated beyond doubt, but they represent the only plausible explanation for these compounds which can be based on the data now available.

SUMMARY AND CONCLUSIONS

All of the minerals examined in this work are structurally similar to apatite, i.e. they have the space group, C_{6h}^2 , as indicated by the similarities of the spacing and intensities of their powder diagrams. There is every indication that the structure assigned to fluor-apatite by Náray-Szabó and by Mehmél is essentially correct.

The formulas, lattice dimensions and densities of certain representative specimens are given in Table 3. These are mostly isomorphous members of several complex series and the properties of the end-members are not known, except in fluor-apatite, ellestadite and hydroxy-apatite. Four of these apatites are carbonate-apatites and the c -dimension of each of these is similar to that of fluor-apatite within the limits of accuracy for the method used. Considerably greater differences were found in the a -dimensions, but it is probably not possible to distinguish between the various members of this group by means of x -ray measurements alone. In favorable cases it may be possible to distinguish the different members by combining a few qualitative tests with x -ray measurements.

The structure of apatite seems to be remarkably stable, permitting a number of rather unusual types of substitution and involving a considerable number of ions. Several different ions apparently substitute for each of the four ions of fluor-apatite.

(1) Calcium is replaced by sodium, potassium, manganese, strontium, magnesium and carbon.

(2) Phosphorus is replaced by sulfur, silicon, arsenic, vanadium and carbon.

(3) Fluorine is replaced by chlorine and oxygen ions and by hydroxyl groups, but not by CO_3 -groups.

(4) Oxygen is replaced by fluorine ions and hydroxyl groups. These substitutions involve differences in valency as well as differences in ionic radii. The most surprising is the substitution of carbon for calcium and

TABLE 3. SUMMARY OF STRUCTURAL DATA FOR VARIOUS MINERALS OF THE APATITE GROUP

Mineral	Structural Composition	a_0	c_0	c/a	Vol. ¹	Calc. D^2	Meas. D
Fluor-apatite	$(\text{Ca}_3\text{F})_2(\text{PO}_4)_6\text{Ca}_4$	9.36	6.88	.735	522	3.187	3.176 ³
Dahllite	$\text{Ca}_6(\text{OH})_2(\text{P}, \text{C})_6\text{O}_{24}$ (Ca, C) ₄	9.41	6.88	.731	528	—	2.93
Dehrnite	$(\text{Ca}, \text{Na})_6(\text{OH})_2(\text{PO}_4)_6$ (Ca, C) ₄	9.31	6.87	.738	516	—	3.04 ⁴
Lewistonite	$(\text{Ca}, \text{K}, \text{Na})_6(\text{OH})_2(\text{PO}_4)_6$ (Ca, C) ₄	9.35	6.89	.737	522	—	3.08 ⁴
Francolite	$(\text{Ca}_3\text{F})_2(\text{P}, \text{C})_6$ (O, OH, F) ₂₄ (Ca, C) ₄	9.34	6.88	.737	520	3.151	3.147
Hydroxy-apatite	$(\text{Ca}_3\text{OH})_2(\text{PO}_4)_6\text{Ca}_4$	9.42 ⁵	6.935 ⁵	.736 ⁵	533 ⁵	3.109	3.067 ⁵
Wilkeite	$\text{Ca}_6(\text{Cl}, \text{F}, \text{OH}, \text{O})_2$ (P, S, Si, C) ₆ O ₂₄ (Ca, C) ₄	9.48	6.91	.729	538	—	3.120
Fermorite	$(\text{Ca}, \text{Sr})_6(\text{F}, \text{OH}, \text{O})_2$ (P, As) ₆ O ₂₄ Ca ₄	9.60	7.00	.729	559	—	3.518 ⁶
Mangan-apatite	$(\text{Ca}, \text{Mn})_6\text{F}_2(\text{PO}_4)_6\text{Ca}_4$	9.33	6.80	.729	513	3.317 ⁷	3.301
Ellestadite	$\text{Ca}_6(\text{Cl}, \text{F}, \text{O}, \text{OH})_2$ (S, Si, P, C) ₆ O ₂₄ (Ca, C) ₄	9.53	6.91	.725	544	3.046	3.068

¹ Vol. = $a^2c \sin 60^\circ \times 10^{24}$ cm³.

² Calc. density = $M/W \times 1.649/\text{Vol.}$

³ According to A. S. Dadson (3).

⁴ According to Larsen and Shannon (12).

⁵ According to Burri, Jakob, Parker, and Strunz (22). The density measurement is for 18°C. and the calculated value of D was not given by these authors but is based on their data.

⁶ According to Smith and Prior (14).

⁷ This calculated value of D was not based upon a complete analysis but upon a determination of MnO, as mentioned above.

for phosphorus, and fluorine for oxygen in one particular instance but oxygen for fluorine in another.

The substitution of monovalent positive ions for bivalent positive ions, compensated by a substitution of monovalent negative ions for bivalent negative ions, is the only plausible explanation for certain alkali-apatites.

The isomorphism of this group is considerably more complicated than has been previously recognized. The value of accurate and complete analyses cannot be overemphasized in connection with any further investigations of these minerals. Analyses which are incomplete or which were made by methods now obsolete, or were made on heterogeneous materials, are almost valueless for this work in view of the complexity of the isomorphism.

REFERENCES

1. HAUSEN, H., Die Apatite deren chemische Zusammensetzung und ihr Verhältnis zu den physikalischen und morphologischen Eigenschaften: *Acta Akad. Aboensis, Math.-Phys.*, vol. 5, no. 3, 62 pp., 1929.
- *2. STARYNKEVIČ-BORNEMAN, J., Sur la présence des terres rares dans les apatites: *Compt. Rend. Acad. Sci. Russie*, vol. 1924, pp. 39-41.
3. DADSON, A. S., A study of some Canadian apatites: *Univ. Toronto Studies, Geol. Ser., Contributions to Canadian Miner.*, no. 35, pp. 51-59, 1933.
4. GRUNER, J. W., and McCONNELL, DUNCAN, The problem of the carbonate-apatites. The structure of francolite: *Zeits. Krist.*, vol. 97, pp. 208-215, 1937.
5. TOKARSKI, J., Neue mikroskopisch-chemische Analysen der Phosphorite aus dem Umgehung von Grodno, (Polen): *Bull. Acad. Pol. Sci. et des Lettres., Cl. Math.-nat., Sér. A.*, vol. 1932, pp. 300-317.
6. LACROIX, A., Sur le minéral à structure optique enroulée constituant les phosphorites holocristalline du Quercy: *Compt. Rend.*, vol. 150, pp. 1388-1390, 1910.
7. McCONNELL, DUNCAN, Spherulitic concretions of dahllite from Ishawooa, Wyoming: *Am. Mineral.*, vol. 20, pp. 693-698, 1935.
8. EDMUNDSON, RAYMOND, Phosphatic concretions near Junction City, Kentucky: *Ibid.*, vol. 21, pp. 529-531, 1936.
9. CHIRVINSKY, V., Über Podolit, ein neues Mineral: *Centrb. Min.*, vol. 1907, pp. 279-283.
10. ——— Zur Frage über Identität des Podolits und Dahllits: *Ibid.*, vol. 1913, pp. 97-102.
11. LARSEN, ESPER S., and SHANNON, EARL V., Two phosphates from Dehrn; dehrnite and crandallite: *Am. Mineral.*, vol. 15, pp. 303-306, 1930.
12. ——— and ——— The minerals of the phosphate nodules from near Fairfield, Utah: *Ibid.*, vol. 15, pp. 307-337, 1930.
13. SHANNON, EARL V., and LARSEN, ESPER S., Merrillite and chlorapatite from stony meteorites: *Am. Jour. Sci.*, [5] vol. 9, pp. 250-260, 1925.
14. SMITH, G. F. H., and PRIOR, G. T., On fermorite, a new arsenate and phosphate of lime and strontia, and tilasite, from the manganese-ore deposits of India: *Mineral. Mag.*, vol. 16, pp. 84-96, 1913.
15. McCONNELL, DUNCAN, The substitution of SiO_4 - and SO_4 -groups for PO_4 -groups in the structure of apatite; ellestadite, the end-member: *Am. Mineral.*, vol. 22, pp. 977-986, 1937.
16. LANDES, K. K., The paragenesis of the granite pegmatites of central Maine: *Am. Mineral.*, vol. 10, p. 368, 1925.
17. LACROIX, A., *Minéralogie de la France*, V. 4, pp. 579-586, 1910.
18. NÁRAY-SZABÓ, ST., The structure of apatite $(\text{CaF})\text{Ca}_4(\text{PO}_4)_3$: *Zeits. Krist.*, vol. 75, pp. 387-398, 1930.

* This paper was not accessible to the writer.

19. MEHMEL, MARTIN, Über die Struktur des Apatits I: *Ibid.* vol. **75**, pp. 323–331, 1930.
20. ——— Beziehungen zwischen Kristallstruktur und chemischer Formel des Apatits: *Zeits. phys. Chem.*, [B] vol. **15**, pp. 223–241, 1931.
21. DAMOUR, A., Sur l'hydro-apatite espèce minérale: *Ann. des Mines*, vol. **10**, pp. 65–68, 1856.
22. BURRI, C., JAKOB, J., PARKER, R. L., and STRUNZ, H., Über Hydroxylapatite von der Kemmlen bei Hospenthal: *Schweiz. Min. u. Petr. Mitt.*, vol. **15**, pp. 327–339, 1935.
23. ROGERS, A. F., Dahllite (podolite) from Tonopah, Nevada, voelckerite, a new basic calcium phosphate; remarks on the chemical composition of apatite and phosphate rock: *Am. Jour. Sci.*, vol. **33**, pp. 475–482, 1912.
24. NACKEN, R., Über die Bildung des Apatits I: *Centrb. Min.*, vol. **1912**, pp. 545–559.
25. HENDRICKS, S. B., JEFFERSON, M. E., and MOSLEY, V. M., The crystal structure of some natural and synthetic apatite-like substances: *Zeits. Krist.*, vol. **81**, pp. 352–369, 1932.
26. CAMERON, F. K., and McCAUGHEY, W. J., Apatite and spodiosite: *Jour. Phys. Chem.*, vol. **15**, pp. 463–470, 1911.
27. PEHRMAN, GUNNAR, Om en apatitförekomst i Åbo: *Fennia*, vol. **45**, no. 13, 12 pp., 1925.
28. HÜTTIG, G. F., Apparat zur gleichzeitigen Druck- und Raummessung von Gasen (Tensi-Eudiometer): *Zeits. anorg. Chem.*, vol. **114**, pp. 161–173, 1920.

SOME APPLICATIONS OF NATURAL COLOR PHOTOGRAPHY IN MINERALOGY

B. M. SHAUB, *Smith College, Northampton, Massachusetts.*

The use of natural color photographs or color transparencies¹ in mineralogy and petrography is still in the initial stage of application, although hand-colored lantern slides have, for a long time, been employed by teachers and lecturers on these subjects. During the past decade improvements have been made in the art of color photography, and at present there are several good color plates on the market. These are known as screen plates. In one type the color elements, red, green and blue-violet, are incorporated in an irregular mosaic forming a color screen, which is placed between the glass plate or film and the photographic emulsion. In another type the color screen involves a separate plate consisting of a regular pattern of square or other ruled elements having the same colors in a gelatin coating. The former is known as a combination screen plate, or film, of which the Lumiere Autochrome film and the Agfa color plate are examples; the latter are referred to as separate screen plates, and the well known Finlay color plate is the outstanding example.

The production of a positive picture on a combination plate involves a comparatively simple reversing process, during the finishing operations. With the separate screen plate a negative is made on a separate panchromatic plate which is exposed while pressed in contact, emulsion to emulsion, with a color screen known as the "taking screen." The glass side of the latter is held towards the lens. The photographic plate is developed, and from it prints are made as in printing ordinary lantern slides. The image consists of a pattern of minute squares of varying density corresponding to the color elements in the screen. "Taking screens" may be used any number of times unless they are damaged by careless handling. Colored positives are obtained by binding "viewing screens" in correct register with the positive prints. The viewing screen is essentially identical to the taking screen, consisting of red, green and blue-violet squares of the same size and arrangement.

The combination plates are made with a very thin and rather delicate emulsion which necessitates an exposure correctly timed within *very narrow limits* in order to reproduce the color faithfully. Incorrect exposures may be remedied to some extent by either reduction or intensification. However, when the error is too great, the plate is lost entirely. The separate plate method has a somewhat greater range of permissible

¹ Wolff, J. E., Lantern slides in natural colors for demonstrating geology and microscopical petrography: *Am. Mineral.*, vol. 15, p. 117, 1930.

exposures and, if the error is too great in this case, the only loss in material is a panchromatic plate.

MAKING DUPLICATES

The combination screen plate may be reproduced in a copying and enlarging camera, but the duplicate always contains more black areas with correspondingly greater absorption and loss of brilliancy. The positive in the separate plate system is made from a negative, and hence any number of positive transparencies may be made and bound in correct register with viewing screens.

ABSORPTION OF LIGHT BY COLOR TRANSPARENCIES

The brilliancy of the plates depends upon the amount of light transmitted. In the combination plate the absorption is over 90 per cent, whereas the separate plate absorbs about 75 per cent² of the light; hence the brilliancy of the latter is two and one-half times greater.

PROJECTION APPARATUS

A brilliant source of illumination is required for projection. However, a 500 watt projector is satisfactory for the normal class room, which can be properly darkened. The heat accompanying this amount of energy is considerable and must be dissipated by some means, otherwise any color plate having a low fusing material incorporated in the screen should not remain in the lantern more than one and one-half to two minutes. Projector manufacturers are now producing lanterns which cool the slides, but there are still opportunities for marked improvement in color plate projectors.

PHOTOGRAPHIC APPARATUS

Many cameras, such as the various view and Graflex models or photomicrographic outfits, may already be adapted to the use of one or more of the various types of color plates after the ground glass is reversed. For some types of cameras special plate holders are required. The variations are too numerous to discuss here, and information concerning this matter may be obtained from the various pamphlets made available by the manufacturers of color plates.

A complete apparatus should be equipped with a series of corrected micro-lenses of, say, 16, 24, 48, 80 and 120 millimeters focal lengths in addition to a 7 or 8 inch lens. These will cover the range of specimens from those as small as 1/16 inch up to 18 inches or larger, depending upon the operating range of the camera.

² Wall, E. J., *Practical color photography*, p. 192. American Photographic Publishing Co., Boston, 1928.

FILTERS

Since all lights have characteristic spectral values and daylight varies in this respect at different times of the day and year, special color filters are necessary, and those recommended by the manufacturers should be used if the type of lamp and voltage are the same as those specified. If the voltage is higher, however, blue will predominate, and if lower, the red will be too strong; hence the strength of the filter should vary if there is any appreciable difference in voltage or type of light from that recommended.

ILLUMINATION

Except for the exposure, the illumination and filter combination is the most important. One should aim to provide a uniform *soft* illumination with a minimum amount of contrast, for the objects are outlined on the plate by the color and not by strong contrast as in black and white photography. For the Agfa color plate photoflood bulbs have very good color values and intense illumination, but the intensity and spectral value of these vary greatly with ordinary voltage fluctuations, and also with the age of the bulb because of the condensation of the filament metal on the interior of the bulb. Projection bulbs of 500 watts capacity and nitrogen-filled Mazda lights produce good results. The latter, on account of their larger size, are more difficult to manipulate, especially for the illuminating of smaller objects. Probably the most reliable and satisfactory kind of illumination for photographing minerals, especially the smaller ones, is some form of arc light. Specimens up to 10 or 12 inches in diameter may be illuminated with two small arc lights by using a 50 mm. hand lens with holders designed to spread the light over the desired area. The same lens may be used to converge the light on small specimens when the latter are to be magnified a number of times. For many minerals a water cell is necessary to prevent overheating the specimen when the arc is focused on a small area. The small arc lamp which is generally used in connection with microscopic and photomicrographic work is not a white-flame arc and, after repeated trials with yellow objects, it was found that for the Finlay-Eastman plate their Wratten filter 4547 should be used with alternating current instead of their filter recommended for use with the white flame arc. Direct current would probably require a filter somewhat lower in density.

DETERMINATION OF CORRECT EXPOSURES

As the success in making a faithful reproduction of a colored object depends to so great an extent on the exposure, it would seem that a formula would be of great value in making this determination. The

factors entering into such a formula,³ however, cannot readily be determined within the permissible variation of the exposure, hence the formulated results are not within the required limits. The chief variables entering into the calculation of an exposure are: the numerical aperture or stop, the magnification, the intensity and kind of illumination, and the color intensity of the principal object to be photographed. Of these factors the numerical aperture and magnification may be accurately formulated. For large objects the light intensity may be determined with an electric photometer, which also includes the color intensity factor providing the colored object to be photographed occupies the major part of the field. For very small objects and photomicrographic subjects the ordinary electric photometer cannot be used on account of the usual design of the instrument.

The early meters for determining photographic exposures consisted essentially of a series of ground glasses having an interposed calibrated diaphragm which was used to vary the intensity of light reflected from the object to be photographed onto some comparison scale. If a camera is used in a dark room and the major part of the light shielded from the operators eyes, or if a focusing cloth is used long enough for the eyes to adjust themselves to darkness, the camera itself involves the essential principles of the early photometers. By closing the lens diaphragm until the most important objects are approaching the limit of being distinctly visible, one has a method which enables the experienced operator to determine the exposure with a fair degree of accuracy. This procedure involves all of the important factors including the color density. If an object is so densely colored that it does not show distinctly on the ground glass, a prolonged exposure is necessary for its reproduction. Considerable judgment is often required in prolonging the exposure so that the darker colored parts are not too greatly under-exposed, and at the same time the weaker colors are not too seriously over-exposed. It is an advantage to work with an intense source of illumination so that the image appears clear and brilliant on the ground glass at full diaphragm opening in order to compose the picture properly and subsequently to determine the exposure. When first starting to make color plates or introducing any marked change in the set-up, the photographer will find it desirable and profitable to make a seven strip test exposure plate of some object having a uniform color intensity over the entire field. To do this, one must start with some estimated exposure, which may be obtained by closing the diaphragm to a point where the ground-glass image is still clear and distinct but where further closing will render many of the parts nearly

³ Whitehead, W. L., Notes on the technique of mineragraphy: *Econ. Geol.*, vol. 12, p. 715, 1917.

invisible. One will soon become accustomed to the best working range in this respect. At the point where the image is still clear and distinct, a good first estimate for a Finlay-Eastman plate is approximately $\frac{3}{4}$ to 1 minute. This should be the exposure for the middle strip of the test plate and the other exposures calculated so the several strips vary by about 12% above and below each successive strip. One should calibrate the dark slide with white lines or use a spacing guide, Fig. 1, to indicate the spacing for the strips; that is, for each position of the slide as it is inserted for the several exposures. Special care is required to prevent

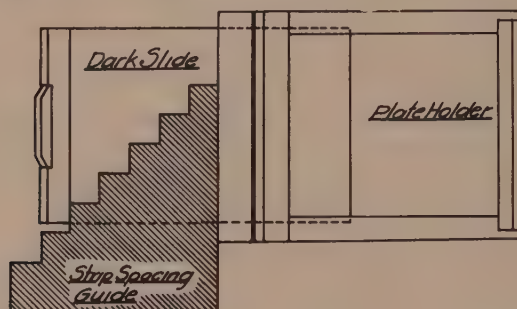


FIG. 1. Sketch of plateholder showing how spacing guide is used for making test exposures of color plates.

the shifting of the plate holder while inserting the slide, for any movement will give a blurred negative. When the test plate is correctly developed, the strip of the Finlay-Eastman negative which has the correct density for printing on No. 3 Azo paper will have the correct density for printing on an Ilford plate to reproduce the correct colors. If the test is made on a combination plate, the strip having the correct colors when developed, would, of course, represent the correct exposure.

PRINTING AND TRANSPARENCIES

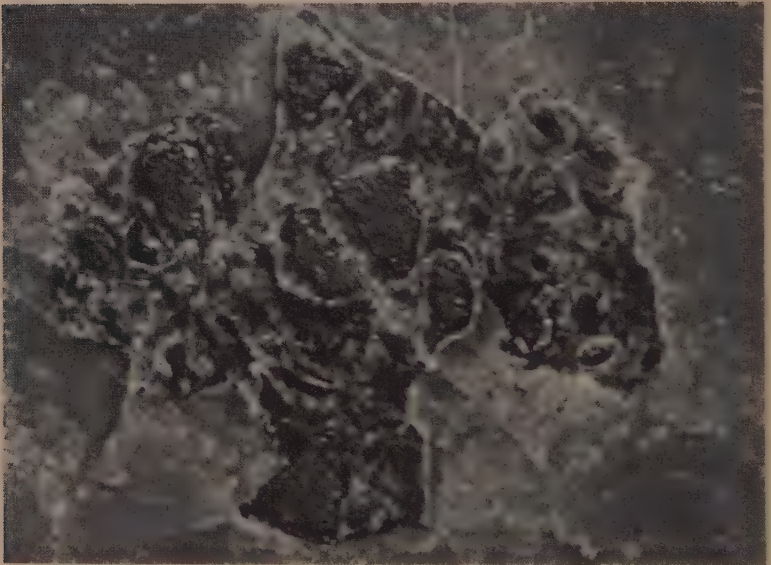
To make positive transparencies from the Finlay-Eastman negatives the writer uses a 15 watt Mazda bulb in a rectangular light house which is supported vertically. The light is diffused and reduced in intensity before leaving the house by passing through a combination of two pieces of flashopal glass which are separated two inches and each of which is covered by two pieces of twenty-pound bond paper. The bulb is 20 inches above an ordinary printing frame which rests in a horizontal position on a table. The average exposure is from 15 to 20 seconds for an Ilford positive plate. This allows sufficient time for shading underex-

PLATE I



A

Emerald from Colombia, South America. $\times = 10$



B

(Finlay Photographs)

Serpentine with stichtite surrounding chromite from near Dundas, Tasmania. $\times = 16$

posed parts of the negative, and thus makes a decided improvement in the color transparency.

The formulae and time of development recommended by the plate manufacturers should be carefully and conscientiously followed, for they are the result of consistent research and application.

APPLICATION TO MINERALOGY AND ALLIED SUBJECTS

One of the first subjects in this field to attract the attention of the color photographer is quite naturally the beautifully colored crystal aggregates, especially the crystals used for cutting gems and precious stones. When photographed these subjects should be so arranged as to show their distinguishing characters. Those who conduct lecture classes will find that natural color lantern slides of properly oriented specimens are, indeed, ideal. With illustrations of this kind the mineral can be described to the entire class simultaneously thus avoiding the mental and physical confusion created by passing around specimens. A series of slides may be made from selected material to cover the usual range of colors, occurrences, crystal forms and other structures of a given species. In this manner excellent museum specimens may be used to the best advantage for instruction, even though they could not be handled by students in either lectures or laboratory work.

With the Finlay color plate a very unexpected degree of perspective is obtained because of the combined effect of the screen and the color shading. The attention of the class is greatly increased, for it is quite the natural and instinctive thing to be inspired by color when our environment is one of color and not merely shades of gray.

One of the surprising advantages of color plates over black and white ones may be seen by comparing the natural color reproduction of a specimen of stichtite, chromite, and serpentine, Plate I, with a black and white reproduction, Fig. 2. In the latter the color tones blend one with the other and the outlines are indistinguishable, while in the color plate they are sharp and distinct. A small emerald crystal $\frac{3}{8}$ of an inch long from Colombia is shown reproduced in color at the top of Plate I and illustrates clearly how the crystallographic features and the color variations may be reproduced from specimen to color plate and then to text illustrations.

Optical mineralogy, which is a difficult subject to the beginning student, is replete with opportunities for the application of natural color illustrations. In the study of mineral fragments in crossed polarized light the student quickly grasps the significance of birefringence and other properties, for the instructor can cover in detail an entire microscope field. He can describe any individual grain or those of particular interest

in regard to their optical orientation, as well as some of their physical properties. In the study of optical interference figures from oriented sections, the character of these and the dispersion of the optic axes can be readily and satisfactorily demonstrated with a set of slides which may be used in a projector or in the laboratory in connection with a view-scope. With the latter a number of slides may be simultaneously examined and compared.

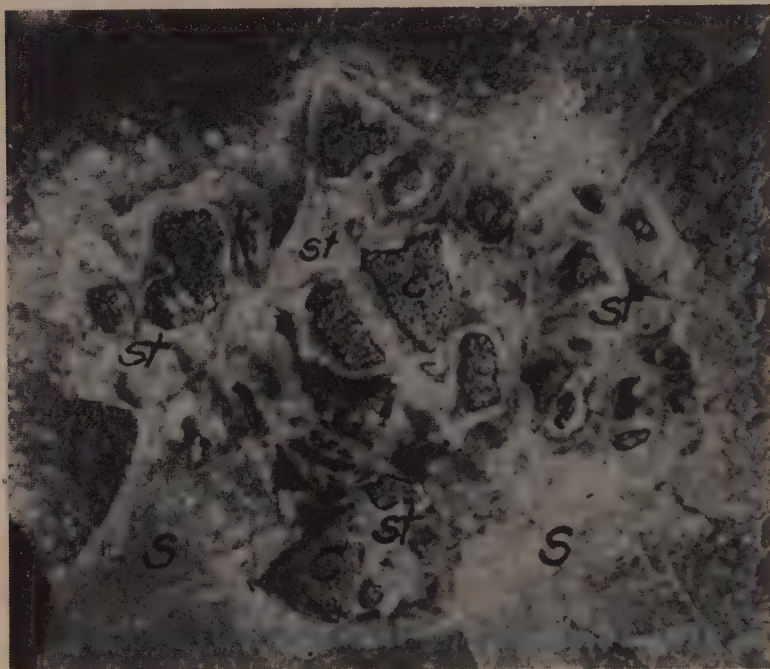


FIG. 2. Serpentine (S) containing stichtite (St) enclosing chromite (C), from near Dundas, Tasmania. Compare with natural color reproduction, B, Plate I.

In petrography, many kinds of structures, textures, mineral associations, alterations, pleochroic effects, and intergrowths may be demonstrated on the screen or viewscope. An advantage of the color plate over the projection microscope lies in the fact that the precise area desired is ready, hence the demonstration is continuous and follows smoothly according to the procedure outlined. A pronounced variation in colors may often be produced in intergrowths of substances having low birefringences by superimposing a gypsum plate. Two color plates of a subject of this nature taken at 90° positions make an excellent demonstration in compensation and retardation.

In mineragraphy, the application of these plates would be most useful in showing the characteristics of micro-crystals⁴ corresponding to the element sought and other micro-crystals likely to occur in the same reactions because of other elements associated in the mineral or occurring as an impurity. A minor use would be in teaching the relationship of minerals in polished sections, but owing to the faint and indistinct colors of most of the metallic minerals in reflected light, one would probably not gain much in this field.

The photographing of very faintly colored, transparent cut-stones in natural color may be unsatisfactory on account of three factors: the first is due to their high luster, which is seldom reproducible to any degree because of the grain of the emulsion and texture of the projection screen; second, the reflection from the facets which produce either very high lights or dark spots; and third, the extremely faint color which is often difficult to reproduce from the rather dense tricolored elements of the color screen. The transparent gems with distinct color and those which are opaque make very beautiful color reproductions.

The writer can commend the use of natural color plates as an exceptionally satisfactory means of visual instruction for both the lecturer and the students; the laboratory teacher will likewise often find their use distinctly superior to other demonstration methods.

The public lecturer in mineralogy will discover in color plates of minerals a magic means of presenting to his audiences the beautiful forms and colors of minerals, as well as the entrancing and perplexing array of polarization colors produced by many petrographic sections. Some of the latter would be difficult for even the most vivid imaginations to overrate in delivering a popular lecture on these natural phenomena.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to the Finlay Colours Ltd., and the Beck Engraving Company, both of 305 East 45th Street, New York City, who together have generously supplied the four engravings necessary to reproduce the natural color photographs, and to Smith College for a special fund to cover the cost of the printing. They together have made it possible to include an appropriate illustration for this paper. He also wishes to thank Mr. Harry G. Beck of New York whose splendid cooperation was greatly appreciated; and, further, to express his indebtedness to Mr. George L. English and Mr. Stephen Varni for permission to photograph the specimens shown on Plate I.

⁴ Putnam, P. C., Roberts, E. J., and Selchow, D. H., Contributions to determinative mineralogy: *Am. Jour. Sci.*, vol. 15 (5th Ser.), pp. 89-102, 253-261, 423-430, 455-460, 1928.

DEFORMATION OF SINGLE CALCITE CRYSTALS UNDER HIGH CONFINING PRESSURES*

DAVID GRIGGS, *Harvard University, Cambridge, Mass.*

ABSTRACT

To supplement the work of investigation of the characteristics of deformation of the calcite aggregates, limestone and marble, some experiments of the deformation of single crystals of calcite under conditions of high confining pressure have been performed. The change in properties with pressure is remarkably different from those observed in the aggregates which suggests the possibility that a considerable portion of the deformation of the aggregates takes place by inter-crystalline deformation. The mechanism of deformation of single crystals does not change with pressure alone, and $10\bar{1}2$ twinning is the dominant means of deformation. It is found that twinning occurs on those twin planes where the deforming force resolved on the plane and in the direction and sense of twinning is a maximum.

INTRODUCTION

In order to understand the mechanism of deformation of crystalline aggregates it is necessary first to know the mechanism of the component crystals. A few experiments have been made on the deformation of calcite single crystals under conditions of high confining pressures in

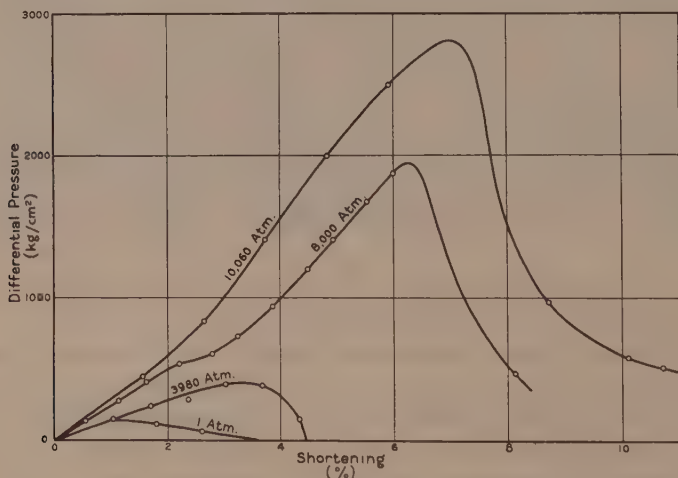


FIG. 1. Stress-strain curves for single crystals of calcite deformed under confining pressures to 1 to 10,000 atmospheres, showing the work hardening of crystals deformed under high pressure.

* Paper No. 43, published under the auspices of the Committee on Geophysics, with the cooperation of the Society of Fellows of Harvard University.

the laboratory and the results are presented in this paper to supplement the data already published on limestone and marble.¹

TECHNIQUE

These experiments were performed in a high pressure cylinder of the type described in an earlier paper² designed to permit observation of the behavior of specimens when surrounded by a confining pressure exerted by a liquid, and then deformed by a differential force applied longitudinally to the specimen. The strain (shortening of the specimen) is measured directly by an extensometer, and the differential pressure is obtained by measuring the force on the piston in contact with the specimen and subtracting from that the components due to the hydrostatic pressure and the friction of the packing.

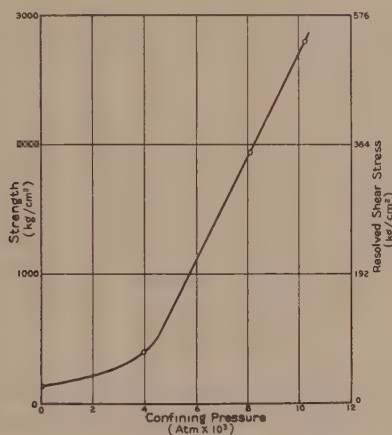


FIG. 2. The increase of strength with confining pressure for calcite single crystals.

The crystals from which these specimens were cut were clear Iceland spar, free from cleavage flaws and also free from any twinning that could be detected visibly. The cleavage fragments were in part obtained from Ward's Natural Science Establishment, and in part were donated by the Harvard Mineralogical Museum.

All the specimens dealt with in this paper were either cylinders or prisms oriented with their long axis parallel to the intersection of two cleavage faces, this direction being selected for ease of preparation. The cylinders were about 1 cm. in diameter and 2 cm. long.

¹ Griggs, David, Deformation of rocks under high confining pressures: *Jour. Geol.*, vol. 44, pp. 541-577, 1936.

² *Ibid.*, p. 545.

No jacket was applied to the specimen. The liquid (kerosene) was in direct contact with the crystal surface.

All the experiments were carried out at room temperature, and at a constant rate of deformation (.005 cm./min. approximately) so that the effects of time and temperature were not measured, but eliminated.

CHARACTERISTICS OF DEFORMATION

The change in the mechanical properties is shown in the accompanying graphs, Figs. 1-3. Figure 1 shows the stress-strain relations as a function of confining pressure. It is interesting that although the plasticity of the crystals is increased by the confining pressure, this effect

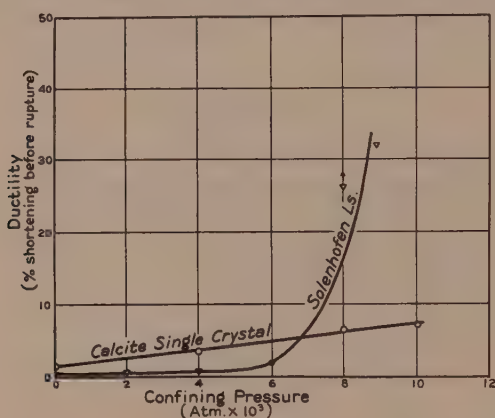


FIG. 3. Comparison of the change in ductility with the pressure in the case of calcite single crystals and in the case of Solenhofen limestone.

is not so great as the increase in strength. Thus, for example, as can be seen from Figs. 2 and 3, the ductility is increased 5.83 times by a confining pressure of 10,000 atmospheres, while the ultimate strength is increased 20.30 times by the same confining pressure.

Curiously enough, just the opposite is true of the Solenhofen limestone, and the figures will be given here for comparison. Ductility is increased 46.0 times by a confining pressure of 8910 atmospheres, while the strength is increased only 4.7 times.

The break in the 8000 atmosphere stress-strain curve is not completely understood. Conceivably it might be due to something giving way within the apparatus, but there was no other indication of this. If it is a true curve of the crystal's behavior, then we have a close approximation to the behavior of many metals at the yield point. This would not be surprising, because calcite aggregates have been shown to have

many properties in common with metal aggregates, but it is very interesting if it occurs thus just as a transient phenomenon during the change in properties as confining pressure is increased.

The writer was surprised to find that the ductility of single crystals of calcite at high pressure was so much lower than that of the aggregates. Marble has been deformed 24% without rupture at 10,000 atmospheres and Solenhofen limestone has been deformed more than 30% at the same pressure without rupture, but as shown, the single crystals of calcite ruptured after only 7% deformation at 10,060 atmospheres.

MECHANISM OF DEFORMATION

In a single crystal it is relatively easy to determine the mechanism of deformation. The first thing which is noticed is that the specimen which was originally a cylinder has been changed so that its section is an ellipse. Figure 4 shows half of this elliptical section in the cylinder deformed at 10,060 atm. In this case the ratio of the long to the short axes was 1.18.

When the thin-sections of Figs. 4 and 5 are set up on the universal stage and the angles between the planes of deformation and the optic axes of the crystals measured, it is found that all the noticeable deformation took place on twin planes of the $10\bar{1}2$ type.

The actual crystal strength may be determined by resolving the compressive force on the twinning plane and in the direction of the twinning, by the formula:

$$\text{Resolved shear stress} = P \sin \alpha \cos \alpha \cos \phi$$

where P = compressive pressure, α = angle between the direction of compression and the normal to the twin plane, ϕ = angle between the projection of the direction of compression and the direction of twinning.

In the case studied, this resolved shear stress is equal to .192 of the compressive pressure on the operative twin plane, and the values of crystal strength are shown in Fig. 2.

It has been shown in the case of metal crystals that this resolved shear stress is the critical factor governing translation and twinning.³ Thus, twinning occurs on those twin planes on which the resolved shear stress is a maximum. In the present experiments there was not sufficient variety of orientation to give much evidence for this. However, investigation of the twinning in marble has shown that this "Law of Maximum Resolved Shear Stress" governs calcite twinning.

A caution to anyone calculating this stress is that it must be not only in the right direction, but in the right *sense* to produce twinning. This

³ Gough, H. J., Crystalline structure in relation to failure of Metals: Edgar Marburg Lecture, *Am. Soc. Testing Materials*, vol. 33, Pt. II, p. 22, 1933.

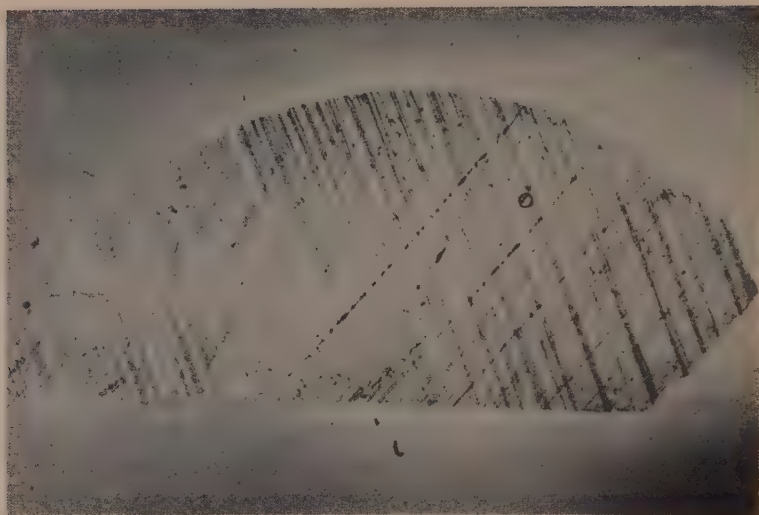


FIG. 4. Photograph of thin-section of single calcite crystal normal to the cylinder axis after deformation at 10,000 atmospheres, showing three sets of twins and cleavage. Magnification 8.5. Nicols uncrossed.

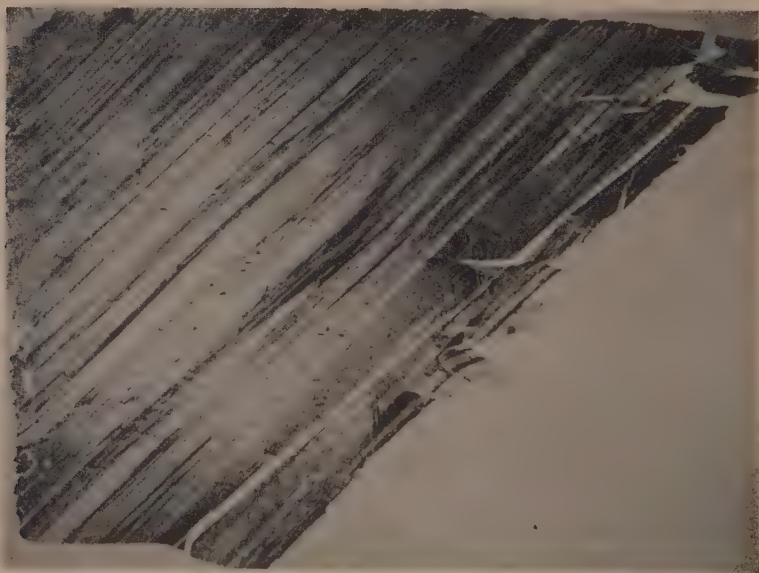


FIG. 5. Photograph of thin-section of calcite crystal parallel to the cylinder axis after deformation at 10,060 atmospheres, showing offsets by the dominant twinning, also other twins and cleavage. Magnification same as above, nicols uncrossed axis of compression is horizontal.

is, of course, obvious from geometrical considerations of the twinning deformation. It is not a necessary condition governing slip, however, since slip may occur in both senses in a given direction in general.

SIGNIFICANCE OF THE RESULTS

Perhaps the most significant observation in this investigation is the low ductility of the single crystals as compared to aggregates of the same crystals. This might immediately lead one to suspect that deformation in aggregates takes place partly through inter-crystalline deformation. It is difficult to determine the relative amounts of intra- and inter-crystalline motion, and at present, this question must be left unanswered, but it is hoped that petrofabric study of deformed marble which Mrs. E. B. Knopf is undertaking in cooperation with the writer may give the complete answer.

This study has shown at least some of the rules of intra-crystalline deformation, and has indicated that at high pressure, the $10\bar{1}2$ twinning is still the most important mechanism of deformation. No pure translation (slip) was noticed, and if present at all, was a very minor factor.

It is possible that the conditions of molecular stability may be altered materially by increased temperature and that under conditions similar to those existing in metamorphism, other mechanisms of crystal deformation become operative. The writer is undertaking a series of high temperature experiments which may give some light on this problem. It is not thought probable that long continued stresses such as might exist in geologic deformations would induce any different reaction, so the effect of time alone is discounted as affecting the *nature* of the deformation. It would certainly affect the *amount* of deformation, and hence the ductility. It is hoped that this factor may be investigated also in the near future.

It is a pleasure to acknowledge the invaluable help of Professor P. W. Bridgman in all the high pressure work. This investigation was made possible by a joint grant from the Committee on Geophysical Research and the Society of Fellows of Harvard University. The writer is also indebted to the Harvard Mineralogy Department for many of the specimens of calcite, which are difficult to obtain.

LEIGHTONITE, A NEW SULPHATE OF COPPER FROM CHILE

CHARLES PALACHE, *Harvard University, Cambridge, Mass.*

ABSTRACT

Leightonite, $\text{CuO} \cdot 2\text{CaO} \cdot \text{K}_2\text{O} \cdot 4\text{SO}_3 \cdot 2\text{H}_2\text{O}$, is a new mineral from Chuquicamata, Chile. It is triclinic, pseudo-orthorhombic, with multiple twinning on (100) and (010). Approximate elements: $a:b:c=0.7043:1:0.4578$; α, β, γ , near 90° . No cleavage; $H=3$; $G=2.95$. Biaxial, negative; X near $b[010]$, Y near $c[001]$, Z near $a[100]$; indices (Na): $nX=1.578$, $nY=1.587$, $nZ=1.595$, all ± 0.002 ; $2V$ about 60° ; $r > v$, fairly strong. Occurs in pale blue prismatic crystals and in fibres filling cross-fibre veins.

The mineral here described for the first time has been known for some years to the geological staff of the Chile Exploration Company at Chuquicamata as probably a new species. It was first found in cross-fibre veins; and on the basis of an incorrect analysis it was doubtfully assigned to the species syngenite. A more accurate analysis by Mr. Carter of the mine staff later showed that this determination was erroneous. Specimens of the mineral and a copy of the later analysis were brought to Cambridge in 1935 by Mr. M. C. Bandy, who made a preliminary study of its crystal form and optical properties. Better material for the crystallographic study, collected and studied optically at the mine by Mr. O. W. Jarrell, was kindly turned over to the Harvard Mineralogical Laboratory for fuller description. My colleagues in the laboratory have all had a hand in the study of this mineral; the writer should have credit for but a small part in the description here presented.

Crystallography. Leightonite, as the new species will be named, is triclinic, as shown by optical examination. The crystals have the appearance of holohedral orthorhombic individuals, but this is the result of combined lamellar twinning on the vertical axial planes of a nearly rectangular triclinic lattice. The faces are consequently multiple in character, giving somewhat blurred signals in which it was not possible to separate the images from the various sub-parallel planes of the twinned complex. For morphological description the crystals are therefore necessarily referred to orthorhombic elements which must be close to the actual triclinic elements of the lattice.

The crystals are mostly slender blades or laths elongated with $[001]$ and flattened on (100), with prominent curved surfaces cutting away more or less of the front edges of the prism and giving to the doubly terminated individuals a sort of hourglass appearance. Such a crystal is shown in Fig. 1; Fig. 2 shows a crystal in which the curvature is absent. Rarely the crystals are equidimensional, as in Fig. 3, and then they are of better quality. Numerous crystals were measured by Mr. Bandy, Dr.

Peacock and the writer. The best measurements are collected in Table 1; the elements, calculated from 80 faces of 5 forms, constitute the basis of the angles in Table 2.

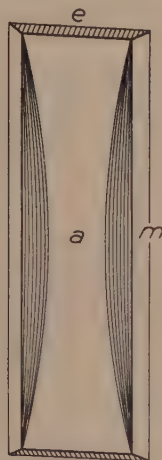


FIG. 1.

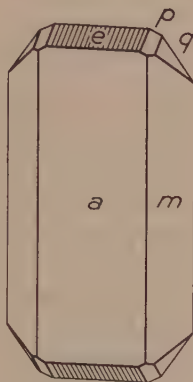


FIG. 2.

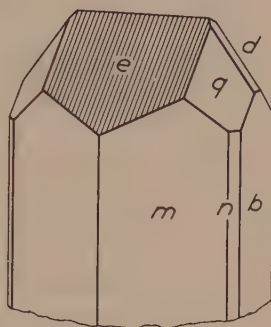


FIG. 3.

CRYSTALS OF LEIGHTONITE

TABLE 1. LEIGHTONITE: MEASURED ANGLES

Forms	Mean		Range		No. of faces	Quality
	ϕ	ρ	ϕ	ρ		
<i>n</i> 130	24°58'	90°00'	23°49'–25°23'	—	11	poor
<i>m</i> 110	54 54	90 00	54 00–55 30	—	36	fair
<i>d</i> 031	0 00	53 47	—	—	1	poor
<i>e</i> 101	90 00	32 52	—	32°45'–33°03'	9	poor
<i>p</i> 111	55 12	38 12	55 15–55 55	37 45–38 43	5	poor
<i>q</i> 131	25 34	56 45	25 00–26 00	56 04–57 04	18	good

TABLE 2. LEIGHTONITE— $\text{CuO} \cdot 2\text{CaO} \cdot \text{K}_2\text{O} \cdot 4\text{SO}_3 \cdot 2\text{H}_2\text{O}$
Triclinic (pseudo-orthorhombic)

$$a:b:c = 0.7043:1:0.4578; \quad p_0:q_0:r_0 = 0.6500:0.4578:1$$

$$q_1:r_1:p_1 = 0.7043:1.5385:1; \quad r_2:p_2:q_2 = 2.1844:1.4198:1$$

Forms	ϕ	$\rho = C$	ϕ_1	$\rho_1 = A$	ϕ_2	$\rho_2 = B$
<i>b</i> 010	0°00'	90°00'	90°00'	90°00'	—	0°00'
<i>a</i> 100	90 00	90 00	—	0 00	0°00'	90 00
<i>n</i> 130	25 19½	90 00	90 00	64 40½	0 00	25 19½
<i>m</i> 110	54 50½	90 00	90 00	35 09½	0 00	54 50½
<i>d</i> 031	0 00	53 56½	53 56½	90 00	90 00	36 03½
<i>e</i> 101	90 00	33 01½	0 00	56 58½	56 58½	90 00
<i>p</i> 111	54 50½	38 29	24 36	59 25	56 58½	69 00
<i>q</i> 131	25 19½	56 39	53 56½	69 04	56 58½	40 58½

Forms. $b\{010\}$ is present only on the crystals of a single specimen one of which is shown in Fig. 3. On these crystals the face is of excellent quality.

$a\{100\}$ is usually broad, determining the habit of the lath-shaped crystals, Figs. 1 and 2.

$n\{130\}$ is a weak form, seen only on the rare crystals of equidimensional habit.

$m\{110\}$ is always present and is the dominant form on prismatic crystals. The faces are bright but often irregularly faceted giving then poor signals.

$d\{031\}$ was observed only once as a poor narrow face, Fig. 3.

$e\{101\}$ is always present with distinct faces deeply striated as shown in Figs. 1 and 2. This form merges insensibly into a steeper curved surface which appears to be the result of partial solution and is not measurable.

$p\{111\}$ is seen only as narrow line faces between q and e .

$q\{131\}$ is the dominant pyramid, producing by its intersection with e the striation on the faces of the latter.

Optical properties. The crystals are pale watery blue to greenish blue, translucent, and faintly pleochroic in tints of blue.

	$n(\text{Na})$	
X near $b\{010\}$	1.578	Negative 2V about 60° $r > v$, fairly strong
Y near $c\{001\}$	1.587	
Z near $a\{100\}$	1.595	

In a section parallel to (010) a crystal shows twin lamellae parallel to $c\{001\}$ with extinction $Y:c\{001\}=3^\circ$. In a section parallel to (001) the lamellae are parallel to $b\{010\}$ and the extinction is $X:b\{010\}=3^\circ$ to 5° . On (100) a crystal shows an internal hourglass structure conforming to that shown by the exterior. Prehnite shows a similar effect. When the crystals are finely crushed each fragment shows twinning effects. These observations lead to the conclusion, already stated, that every crystal of leightonite is a complex of twin lamellae resulting from combined twinning on the subrectangular planes (100) and (010) of a triclinic structure.

Physical properties. Cleavage none. $H=3$. $G=2.95$ (by suspension in methylene iodide and bromoform).

Chemical composition. Leightonite is a hydrous sulphate of copper, lime and potash, with the empirical formula: $\text{CuO} \cdot 2\text{CaO} \cdot \text{K}_2\text{O} \cdot 4\text{SO}_3 \cdot 2\text{H}_2\text{O}$.

Occurrence. Leightonite occurs at Chuquicamata, Chile, in the great open cut. O. W. Jarrell reports that it is found quite abundantly on the east and west sides of the open pit near the south end. It appears to be limited to a zone within 50 meters of the original surface and is found in

TABLE 3. LEIGHTONITE: ANALYSES

	1	2	3	4	5
CuO	12.2	11.24	11.97	0.1505 = 1×0.1505	12.39
CaO	17.3	17.50	18.41	0.3283 = 2×0.1641	17.45
K ₂ O	13.8	13.62	13.93	0.1479	14.68
Na ₂ O	tr.	0.98	0.56	0.0090	
SO ₃	48.8	50.75	49.33	0.6162 = 4×0.1541	49.87
H ₂ O at 105°	0.2	5.98	5.71	0.3170 = 2×0.1585	5.61
H ₂ O at 900°	6.8				
Insol.	0.5				
	99.6	100.07	99.91		100.00

1. Cross-fibre material. Carter, analyst.
2. Cross-fibre material. Gonyer, analyst.
3. Crystals. Gonyer, analyst.
4. Molecular proportions from analysis 3.
5. Composition of $\text{CuO} \cdot 2\text{CaO} \cdot \text{K}_2\text{O} \cdot 4\text{SO}_3 \cdot 2\text{H}_2\text{O}$.

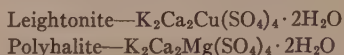
borderland material, never in rich ore. Leightonite was formed only under conditions of low acidity. Its associates are chiefly atacamite and kröhnkite, never antlerite. It forms networks of crystals in cracks, cementing rock fragments; and it completely fills cross-fibre veins. The mineral is similar in appearance to kröhnkite but has a paler blue color.

Name. Leightonite is named in honor of Dr. Tomas Leighton, Professor of Mineralogy at the University of Santiago, Chile.

THE RELATION OF LEIGHTONITE TO POLYHALITE

M. A. PEACOCK, *University of Toronto, Toronto, Canada.*

The well-defined new mineral leightonite, described by Palache in the preceding communication, is especially interesting since it proves to be the copper homologue of the magnesium salt polyhalite. The chemical formulae of the two species compare as follows:



Homologous compounds are commonly homeomorphous. Both leightonite and polyhalite are triclinic, but in their present settings they do not show the expected geometrical similarity. In the natural pseudo-orthorhombic setting adopted by Palache, leightonite is developed prismatically with the axis $c[001]$ and twinned on the sub-rectangular planes $a(100)$ and $b(010)$. For polyhalite Görgey (1915) chose a pseudo-monoclinic lattice:

$$a:b:c=0.9314:1:0.8562; \alpha=92^\circ 29', \beta=123^\circ 04', \gamma=88^\circ 21'.$$

With reference to this lattice the crystals are commonly elongated with the axis $a[100]$ and twinned on the sub-rectangular planes $b(010)$ and $c(001)$.

When polyhalite is turned forward about the normal to (010) until $[100]$ comes into the vertical position the two crystal species agree in habit and twinning. Graphically the following planes come to near coincidence:

Polyhalite (Görgey)	Leightonite (Palache)
(100)	(10 $\bar{1}$)
(010)	(010)
(001)	(100)
($\bar{2}$ 12)	(111)

This correspondence gives the transformation:¹

$$\text{Görgey to Palache: } \frac{1}{2}01/010/\frac{1}{2}00.$$

Applying the transformation to Görgey's elements we obtain the follow-

¹ The terms of the transformation formula are here written in the correct fractional form, as proposed by Dr. J. D. H. Donnay in a personal communication. In this form the transformation yields axial lengths and indices with the correct absolute values. If the transformation formula is cleared of fractions, as has always been done in the past, the resulting axial lengths and indices are proportional to the absolute values, which is adequate for morphological purposes if lattice centering is neglected.

ing elements of polyhalite which show the expected agreement with Palache's elements of leightonite:²

Polyhalite			
$a:b:c=0.7176:1:0.4657$;	$\alpha=90^{\circ}39'$,	$\beta=90^{\circ}06\frac{1}{2}'$,	$\gamma=91^{\circ}53'$
Leightonite			
$a:b:c=0.7043:1:0.4578$;	$\alpha=90^{\circ}$,	$\beta=90^{\circ}$,	$\gamma=90^{\circ}$

The chemical similarity of the two species is thus accompanied by the usual similarity of form.

Table 1, computed by Mr. C. W. Wolfe, is an angle-table for the accepted forms of polyhalite, after Görgey, in Palache's setting. Comparing the form-symbols with those of Görgey (1915, p. 84) it will be found that an important simplification has been achieved.

TABLE 1. POLYHALITE— $K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$

Triclinic; pinacoidal—I

$$a:b:c=0.7176:1:0.4657; \quad \alpha=91^{\circ}39', \quad \beta=90^{\circ}06\frac{1}{2}', \quad \gamma=91^{\circ}53'$$

$$p_0:q_0:r_0=0.6490:0.4660:1; \quad \lambda=88^{\circ}20\frac{1}{2}', \quad \mu=89^{\circ}50\frac{1}{2}', \quad \nu=88^{\circ}06\frac{1}{2}'$$

$$p_0'=0.6493, \quad q_0'=0.4661; \quad x_0'=0.0019, \quad y_0'=0.0289$$

Forms	ϕ	ρ	A	B	C
<i>b</i> 010	0°00'	90°00'	88°06½'	0°00'	88°20½'
<i>a</i> 100	88 06½	90 00	0 00	88 06½	89 50½
<i>m</i> 110	53 05½	90 00	35 01	53 05½	88 55
<i>M</i> 110	124 25½	90 00	36 19	124 25½	90 51
<i>o</i> 120	144 32	90 00	52 38½	144 32	91 17
<i>v</i> 130	154 46	90 00	66 39½	154 46	91 27
<i>w</i> 140	160 36	90 00	72 29½	160 36	91 31½
γ 011	0 13	26 20	89 04	63 43½	24 37
<i>h</i> 021	0 06½	43 52	88 37	46 08	42 12½
<i>s</i> 011	179 45½	23 37	90 39½	113 37	25 16
<i>x</i> 101	85 35	33 08	56 56	87 35½	32 54
<i>y</i> 101	— 89 19½	32 54½	89 38	89 50½	33 02
ϵ 111	51 34½	39 43	59 06½	66 36	38 37½
<i>e</i> 111	122 34½	37 41	59 44	109 13	38 30½
<i>z</i> 111	— 53 47½	38 43½	119 29½	68 18½	37 51½
<i>u</i> 111	— 125 19	38 25	121 13½	111 03	39 29
δ 131	24 11½	57 48	68 01	39 28½	56 15
<i>d</i> 131	154 13½	56 15½	70 19½	138 29½	57 42½

² The details of the method of recomputing triclinic elements to a new setting by means of the transformation formula were recently given by Wolfe (1937).

<i>l</i>	$\overline{3}13$	— 75 $51\frac{1}{2}$	33 43	122 $14\frac{1}{2}$	82 $12\frac{1}{2}$	33 27
<i>n</i>	$\overline{1}31$	— 24 43	57 08	109 01	40 $16\frac{1}{2}$	55 $40\frac{1}{2}$
<i>t</i>	$\overline{1}51$	— 15 28	67 36	102 $32\frac{1}{2}$	26 $59\frac{1}{2}$	66 02
λ	$\overline{3}\overline{1}3$	—102 $51\frac{1}{2}$	33 $34\frac{1}{2}$	122 53	97 05	34 05
ξ	$\overline{2}\overline{1}2$	—109 $12\frac{1}{2}$	34 25	122 $39\frac{1}{2}$	100 43	35 06
ν	$\overline{1}\overline{3}1$	—155 03	56 54	112 $13\frac{1}{2}$	139 25	58 27
τ	$\overline{1}51$	—164 26	67 $28\frac{1}{2}$	106 05	152 51	69 06
<i>f</i>	$\overline{3}\overline{1}1$	100 $50\frac{1}{2}$	63 15	29 25	99 $40\frac{1}{2}$	63 $28\frac{1}{2}$
<i>g</i>	331	123 49	66 $54\frac{1}{2}$	41 $40\frac{1}{2}$	120 $47\frac{1}{2}$	67 45
<i>i</i>	5 $\overline{1}1$	95 49	72 58	18 39	95 $33\frac{1}{2}$	73 02

The form series of polyhalite and leightonite, in the adopted pseudo-orthorhombic setting, exhibit an interesting feature that indicates the nature of the structural lattices of the two species. This lies in the absence of forms which we would expect to be present if the chosen pseudo-orthorhombic lattice were of the primitive mode. These absences show more clearly in polyhalite, which has the more fully developed form-series, and they are particularly evident in the gnomonic projection (Fig. 1) in which the radial lines are normals to the known vertical planes with symbols (hkl), the filled points are known planes with symbols (hkl), the blank points are known planes with symbols (hkl), where l is greater than 1. For the sake of simplicity and without introducing any significant error we may consider the lattice as orthorhombic and neglect the signs of the indices in the following consideration of lattice-plane spacings in relation to form development.

Whether we accept the Law of Bravais, or the Principle of Simplest Indices, such absences as (121), (141), are striking in view of the presence of (111), (131), (151); further, (221) is to be expected since (111), (331) are present; again (211), (411) should appear since (311), (511) are known.

These morphological absences are directly comparable to the familiar röntgenographic extinctions due to lattice centering, and they are interpreted in a similar manner. Lattice centering of the several possible types systematically halves the spacings of certain sets of planes in the simple lattice and thus doubles the corresponding indices (reciprocal lattice coordinates). Certain lattice planes (hkl) become ($2h \cdot 2k \cdot 2l$); (hkl) is extinguished as an x -ray diffraction spot, and the morphological importance of planes with the apparent symbol (hkl) is halved in keeping with the halved spacing, or reticular density, of the plane (Law of Bravais), and the increased complexity of the indices (Principle of Simplest Indices).

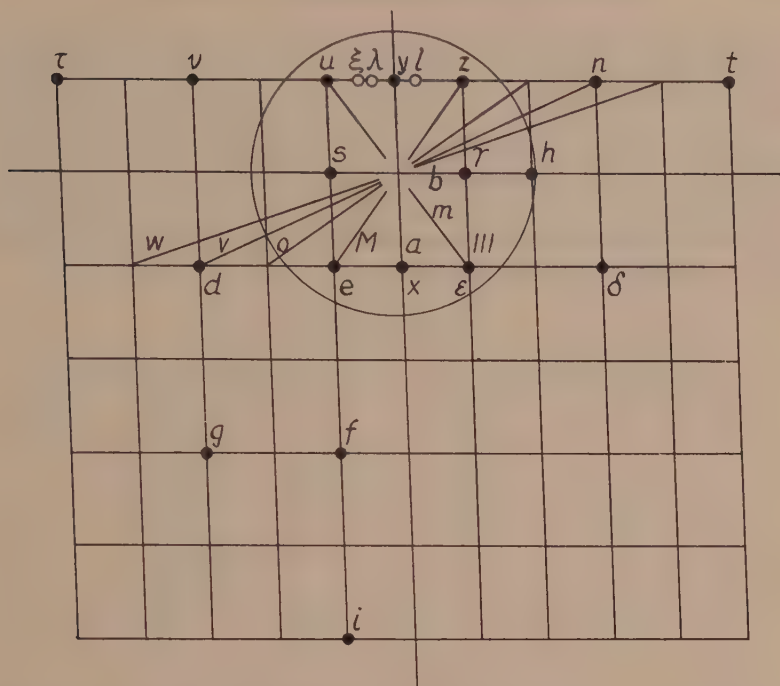


FIG. 1. Polyhalite. Gnomonic projection of the known forms in the pseudo-orthorhombic setting (Table 1). The gnomonic net is the first layer $|hk1|$ of the reciprocal lattice corresponding to the face-centered cell in the direct lattice (Fig. 3).

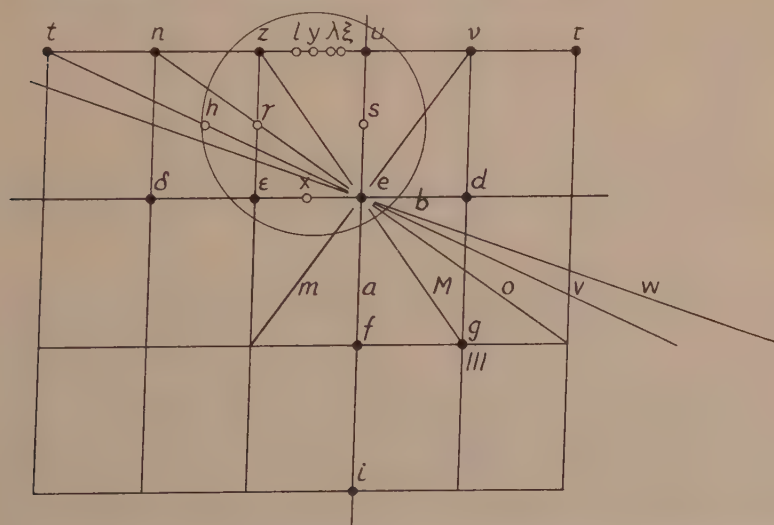


FIG. 2. Polyhalite. Gnomonic projection of the known forms in the normal setting. The gnomonic net is the first layer $|hk1|$ of the reciprocal lattice corresponding to the simple cell in the direct lattice (Fig. 3).

In the case of polyhalite the morphological absences indicate that the pseudo-orthorhombic lattice is an F -lattice in which all the faces of the primitive cell are centered. This type of centering results in halving the spacings of all planes whose indices in the primitive lattice do not conform to the law: h, k, l , all even, or h, k, l , all odd. It will be noticed that all the missing points mentioned above fail to conform to the F -lattice requirement, and thus we understand the failure of the corresponding planes to develop as crystal planes.

TABLE 2. POLYHALITE: INDICES AND SPACINGS

Pseudo-orthorhombic— P			Pseudo-orthorhombic— F		
Form	hkl	d	Form	hkl	d
b	010	4.29	b	020	2.25
a	100	3.07	ϵ		
m			e		
M			z	111	1.55
—	001	2.00	u		
γ			a	200	1.54
s			m		
o			M	220	1.24
x			δ		
y			d		
e			n	131	1.08
z			v		
u			—	002	1.00
h			γ		
—	021	1.45	s	022	0.91
—	210	1.45	f		
—	121	1.31		311	0.89
v	130	1.29	o		
—	201	1.21	x	240	0.88
			y	202	0.84
			g	331	0.76
			t	151	0.76
			τ		
			h	042	0.73

Table 2 gives the indices (hkl) and the relative spacings³ (d) of the thirteen planes with the greatest spacings in the primitive (P) lattice and in the face-centered (F) lattice. The important forms of polyhalite are, according to Görgey, *b a z y t M l o d n*, using the letters adopted in

³ Obtained by a graphical method which will be described elsewhere.

Table 1. The *F*-list clearly gives the better correspondence between morphological development and reticular spacings; and trials with the remaining possible modes of centering quickly show that they do not come into consideration.

Since the pseudo-orthorhombic lattice-cell of polyhalite is evidently face-centered and therefore a quadruple cell, we are confronted with the question: Would it not be proper to refer the morphology of polyhalite,

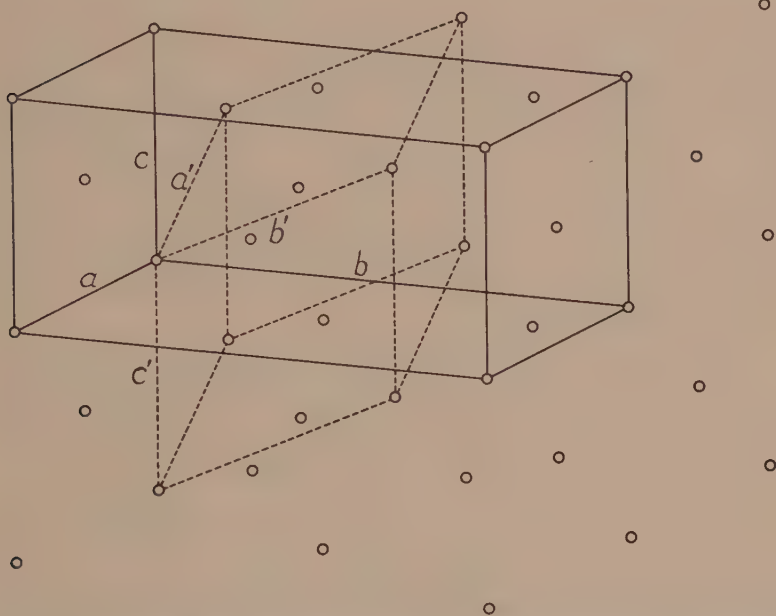


FIG. 3. Polyhalite. The direct lattice inferred from the morphology, showing the face-centered pseudo-orthorhombic cell (full lines) and the simple cell of the normal setting (broken lines).

and the homeomorphous species, leightonite, to a simple cell according to the principles of the normal triclinic setting recently proposed by the writer (1937) A, B) and adopted for the presentation of the morphology of several triclinic species? Figure 3 shows the lattice of polyhalite in which one pseudo-orthorhombic face-centered cell and one simple cell conforming to the requirements of the normal triclinic setting are outlined. The axes a' , b' , c' , of the simple cell have the indices $[\frac{1}{2}0\frac{1}{2}]$, $[0\frac{1}{2}\frac{1}{2}]$, $[00\bar{1}]$, with respect to the axes a , b , c , of the quadruple cell; consequently the transformation reads:

$$\text{Pseudo-orthorhombic to Normal: } \bar{\frac{1}{2}}0\frac{1}{2}/0\frac{1}{2}\frac{1}{2}/00\bar{1}$$

In the normal setting the forms of polyhalite appear as in Fig. 2, which may be compared with Fig. 1 giving the projection of the pseudo-orthorhombic setting. The planes (100) and (010) and the axes [001] are parallel in the two settings; but since the vertical axes have opposite senses the one projection is the mirror image of the other. In the normal setting the basal plane slopes considerably to the front-right, and since the projection elements p_0' , q_0' are double the corresponding values in the pseudo-orthorhombic setting, the volume of the reciprocal lattice cell in the normal setting is four times the volume of the reciprocal lattice cell in the pseudo-orthorhombic setting. The volumes of the direct lattice cells are in the converse relation. The normal setting gives some further simplification of indices since there are no systematic omissions.

The normal setting thus has certain advantages, and this setting should properly be adopted if absolute uniformity of treatment were the prime consideration. At the same time the normal setting would not reveal the remarkable pseudo-symmetry of the quadruple cell; and consequently the use of the pseudo-orthorhombic lattice is justified. The case is, in fact, exactly covered by the provision contained in the following statement (1937 A, p. 616):

The cases examined constitute a large proportion of the known triclinic minerals occurring in well-developed crystals, a sufficient number to warrant the conclusion that the normal setting, based on the smallest structure cell, is the proper setting for triclinic crystals except when well-marked pseudo-symmetry of habit points definitely to a simple multiple lattice of the structure lattice as the better morphological framework.

The structure lattices, it is true, have not been determined for the two minerals in question: the foregoing discussion rests wholly on morphological data in the light of the Law of Bravais. But in other cases similar considerations have led to the structural lattice. If a rigorous röntgenographic determination can be made, in spite of the difficulties which will arise from the complicated twinning, it will be interesting to compare the results with those obtained from the morphology.

SUMMARY

Leightonite— $\text{K}_2\text{Ca}_2\text{Cu}(\text{SO}_4)_4 \cdot 2\text{H}_2\text{O}$ is the copper homologue of polyhalite— $\text{K}_2\text{Ca}_2\text{Mg}(\text{SO}_4)_4 \cdot 2\text{H}_2\text{O}$. Suitably re-oriented polyhalite is similar to leightonite in its geometrical elements, habit and twinning. In the adopted orientation, in which an angle-table is given for polyhalite, the lattices of both species are triclinic with marked orthorhombic pseudo-symmetry. Morphological considerations indicate that this lattice is all-face-centered.

REFERENCES

- GÖRGEY, R. (1915): Über die Krystallform des Polyhalit—*Min. Pet. Mitt.*, vol. **33**, pp. 48–102.
- PEACOCK, M. A. (1937 A): On the Crystallography of Axinite and the Normal Setting of Triclinic Crystals—*Am. Mineral.*, vol. **22**, pp. 588–624.
- (1937 B): The Normal Triclinic Setting: Correction—*Am. Mineral.*, vol. **22**, pp. 987–989.
- WOLFE, C. W. (1937): Re-orientation of Römerite—*Am. Mineral.*, vol. **22**, pp. 736–741.

HEAVY MINERALS IN THE GRANITIC ROCKS OF THE YOSEMITE REGION

ADOLF PABST, *University of California, Berkeley, California.*

The Sierra Nevada batholith consists of a large number of intrusive units. In some parts of the Sierra Nevada these units can be clearly distinguished by careful mapping but this has been done in only a few scattered areas. The best-known profile of the granitic rocks is in the Yosemite region where Calkins¹ has defined and described the rocks across the entire width of the Sierra Nevada, and Cloos² has mapped the structural features.

The present study was undertaken to determine whether the intrusive units established by other methods can be distinguished by their heavy mineral assemblages. A grant from the Board of Research of the University of California to defray a part of the field and laboratory expenses is gratefully acknowledged.

The field work was done in 1931 and 1933. Large, fresh, and typical specimens were collected from about fifty localities in the Yosemite region and the northern Sierra Nevada. Only the results on the rocks of the Yosemite region are here reported. Scattered observations on rocks from other localities suggest that the results may be typical for the granitic rocks of the Sierra Nevada.

METHODS

Samples averaging about 275 grams were crushed in a jaw crusher and then further crushed in a disc crusher or iron mortar with frequent sieving to 60 or to 100 mesh. The samples were then reweighed, washed to remove powder, and again reweighed. The washing loss was kept below 15% in all cases and the total loss below 20% in most cases.

Two 10 or 15 gram portions of each of the samples thus prepared were treated with bromoform of density 2.88. The light fractions included all muscovite and chlorite and a little altered biotite. After removal of magnetite from the heavy fraction by a hand magnet, separation into further fractions by use of an electromagnet was attempted but did not yield consistent results. This may have been due to the fact that most of the rocks contained far more ordinary ferromagnesian minerals than accessories. Accordingly, the procedure after removal of magnetite was varied to fit each sample. One of the duplicate fractions was boiled briefly

¹ Calkins, F. C., The granitic rocks of the Yosemite region: *U. S. Geol. Survey, Professional Paper* **160**, pp. 120-129, 1930.

² Cloos, E., Der Sierra-Nevada Pluton in Californien: *Neues Jahrb. f. Min. etc.*, **BB 76B**, pp. 355-450, 1936.

with dilute hydrochloric acid, resulting in the solution of apatite and leaching of biotite without affecting any of the other heavy minerals, whereupon the leached biotite was separated by a second bromoform treatment. In those cases where hornblende was an important constituent it was separated from sphene and other heavy accessories by treatment with a thallium formate solution having a density of about 3.3. In a few cases the thallium formate separation was also used without preliminary acid treatment, thus saving the apatite.

In view of the great bulk of many of the heavy fractions no complete grain counts were made. Instead several partial counts were made on each of the separations obtained as just described. In some cases the proportions of the accessories could only be estimated by comparison of counts on several separations. In biotite-rich rocks, apatite could be counted only in the presence of a flood of biotite. If the abundance of apatite was to be compared with that of sphene and zircon, but zircon was not sufficiently abundant for accurate estimate in the presence of biotite, then apatite and sphene were counted in the fraction containing biotite, whereas zircon and sphene were counted in the weighed fraction denser than 3.3, obtained from the initial separation, and the proportions of all three established in a satisfactory manner.

All rocks were examined in two or more thin-sections. One or two micrometric analyses were made of each of the finer grained rocks to check the other work. All separations that failed to check with their duplicates or with the micrometric analyses were repeated on new crushings.

MATERIAL

The location of each specimen is shown on the sketch map of Fig. 1 which covers precisely the same area as Calkins' "Generalized Geologic Map of Part of the Yosemite Region, California."³ The symbols used are those of Calkins who has described each of the types collected. The El Capitan granite and the Bridalveil granite had been named earlier by Turner.⁴

The rocks examined are listed in the legend of Fig. 1 in order of their presumed age, the Johnson granite porphyry being youngest. Calkins recognized several other types not included in this list. The Half Dome quartz monzonite, the Cathedral Peak granite and the Johnson granite porphyry make up an eastern mass of concentric intrusions. The remaining rocks, all exposed in the wall of Yosemite Valley, are older than this eastern mass but their age relations are somewhat uncertain.

³ U. S. Geol. Survey, *Professional Paper* 160, plate 51, 1930.

⁴ Turner, H. W., The Pleistocene geology of the south central Sierra Nevada with especial reference to the origin of Yosemite Valley: *California Acad. Sci. Proc.*, 3rd ser., vol. 1, pp. 304, 308, 1900.

RESULTS

Table 1 gives the results of the examination of the heavy concentrates. Numerical indications, with the exceptions noted, refer to weight percentages and are based on actual weighings. The index figures and the percentages of magnetite are based on duplicate determinations. The remaining numbers, for the most part, are based on single determinations. The qualitative indications of frequency are based on multiple, but incomplete, grain counts. In each case the minerals listed as abundant, or very common, are of less frequent occurrence than the least abundant of those for which percentage figures are given. Whereas, the relative abundance of the accessories in a particular rock may be satisfactorily indicated in this way, it is feared that these indications need some adjustment in comparing different samples, especially where there is a great difference in the index figure. In a few cases it might have been possible to indicate more than five orders of abundance. This was avoided in order not to burden the table and to keep the presentation as uniform as possible.

There has been a great variation in the methods of studying accessory minerals and the manner of presenting the results. Taylor⁵ has recently stressed the necessity of using quantitative methods. It is felt that quantitative methods have been carried as far as is feasible in the present study. The purely qualitative statement of a part of the results is used to avoid a semblance of accuracy which would not be justified by the data.

Varietal features, though characteristic in a few of the rocks, are not recorded in the table because features suitable for comparison of the whole series were not found.

The number of accessory minerals is small in all of the rocks. In the suite as a whole, sphene, apatite and zircon are the most important accessories, differences being limited largely to changes in the proportions of these three. Sphene is a common constituent of all granitic rocks of the Yosemite region. Pyrite is common in some specimens but cannot be considered characteristic of any of the rock types. Tourmaline is only a sporadic constituent and rutile, anatase and spinel were only found as occasional grains, not certainly identified.

The differences between the accessory minerals of closely related rocks are striking in spite of the small number of varieties concerned. For instance, apatite is uniformly more abundant in the El Capitan granite than in the Taft granite, whereas the Taft granite is not only richer in

⁵ Taylor, J. H., A contribution to the study of accessory minerals of igneous rocks: *Am. Mineral.*, vol. 22, pp. 686-700, 1937.

TABLE 1. HEAVY MINERALS IN THE GRANITIC ROCKS OF THE YOSEMITE REGION

Index figure	Magnetite	Biotite	Hornblende	Sphene	Apatite	Zircon	Ilmenite	Augite	Allanite	Zoisite	Clinzoisite	Epidote	Tourmaline	Pyrite
Johnson granite porphyry														
jg 1 Soda Springs	1.7	0.7	0.8	1	vc	1	a	—	vt	1	—	c	—	—
jg 2 Soda Springs	1.9	0.8	0.8	1	c	vt	a	—	c	—	—	vc	—	—
Cathedral Peak Granite														
cpg 1 Polly Dome	8.6	1.6	5.0	1.3	c	vt	—	—	—	1	—	1	—	—
cpg 2 Fairview Dome	4.4	1.2	2.2	0.5	c	vt	—	—	—	—	—	1	—	—
cpg 3 Tuolumne Meadows	4.8	1.6	1.5	1.1	0.5	1	—	—	—	—	—	1	—	—
cpg 4 Tuolumne River	5.3	1.2	2.4	1.9	0.6	vt	—	—	—	—	—	1	—	—
Half Dome quartz monzonite														
hdm 1 Mirror Lake	7.5	1.0	4.2	1.8	vc	vt	—	—	—	—	1	vt	—	—
hdm 2 Mirror Lake	9.1	1.4	4.4	2.5	0.5	vt	?	—	—	—	1	vt	—	—
hdm 3 Tenaya Creek	10.8	2.0	4.2	3.6	0.9	c	—	vt	—	—	—	1	—	—
hdm 4 Polly Dome	10.9	2.1	4.9	2.7	1.1	1	—	vt	—	—	vt	vt	—	—
hdm 5 Merced Lake	12.0	2.0	6.5	2.5	0.8	vt	?	—	—	—	—	1	—	—
Sentinel granodiorite														
sg 1 near Taft Point	21.1	2.1	9.8	8.1	1.1	c	—	—	—	—	vt	—	—	—
sg 2 Sentinel Dome	19.5	2.2	11.3	4.7	1.1	a	—	—	—	—	—	—	—	—
sg 3 Allouette Trail	27.9	1.4	13.4	12.2	0.7	a	?	c	—	—	—	1	1	—
sg 4 Glacier Point	25.4	1.3	10.9	9.2	0.8	a	?	—	—	—	—	vc	—	—
sg 5 McGee Lake	27.7	2.4	15.0	12.0	0.8	a	—	c	—	—	—	1	—	—
Bridalveil granite														
bvg 1 Bridalveil Falls	9.4	0.5	8.7	1	vc	1	—	—	1	—	1	a	—	1
Taft granite														
tg 1 Sec. 18, R. 22E., T. 3 S.	1.0	0.3	0.6	1	vc	c†	vc	1	?	—	vt	—	vt	1
tg 2 Taft Point	1.9	0.2	1.5	vc	1	c†	c	c	?	—	vt	—	1	c
tg 3 foot of El Capitan	2.7	0.5	2.0	1	vc	vc†	vc	1	—	—	c	—	—	—
tg 4 McGee Lake	1.3	0.4	0.7	1	1	c	vc	—	—	—	vc	—	—	1
El Capitan granite														
eg 1 near Sentinel Dome	2.7	0.8	1.8	1	vc	1	—	—	vt	vt	—	1	—	—
eg 2 Turtleback Dome	3.9	0.6	3.2	vt	a	c	—	—	1	c	—	vc	—	—
eg 3 Rock Point	11.0	0.9	6.3	a	vc	1	—	—	1	1	—	c	—	—
eg 4 near Tamarack Flat	6.2	0.7	5.3	1	a	vc	—	—	vt	vt	—	c	—	—
eg 5 Big Oak Flat Road	8.9	0.1	8.7	vt	a	c	—	—	1	1	—	c	—	—
Diorite and gabbro														
dg 1 Glacier Point Road	48.8	0.2	1.0†	42.5†	vc	—	—	4.8†	—	—	—	vt	—	1
dg 2 El Capitan	32.0	0.1	14.0	17.3	a	1	—	—	—	—	—	1	—	—
dg 3 Oak Flat Road	38.7	0.2	16.4	21.7	0.3	vc	1	—	—	—	—	1	—	—

a = abundant; vc = very common; c = common; 1 = rare; vt = very rare.

* Includes unidentified heavy, black, non-magnetic grains.

† Two varieties of zircon; see text.

‡ Figures from micrometric measurements

zircon but contains two distinct varieties of zircon in contrast to all of the other rocks in which it was impossible to distinguish more than one variety.

The rocks described as diorite and gabbro, probably belonging to several different intrusions, show great differences in the accessory minerals.

THE MINERALS

Sphene. Euhedral crystals of sphene are megascopically conspicuous in the Cathedral Peak granite, Half Dome quartz monzonite, and Sentinel granodiorite. Most of the grains in the concentrates are fragments of larger crystals, but from thin-section observations and the appearance of small crystals it can be said that sphene is dominantly euhedral in the Yosemite rocks, showing the familiar "envelope" habit. Exceptions occur in the Sentinel granodiorite which carries both euhedral and anhedral sphene, and in the diorite and gabbro in which the sphene is mostly anhedral. Most of the sphene is clear and pale colored in small fragments. Only a few pieces were found to enclose other crystals.

Apatite. A short prismatic habit with pyramid and basal plane terminations is common to apatite in all of the rocks. The size of the crystals varies greatly in most specimens, maximum dimensions of about 0.1×0.2 mm. being common. No cloudy, altered or embayed apatite was seen and only a few of the larger crystals from the Half Dome quartz monzonite and the Sentinel granodiorite showed rod-like cores. Large anhedral fragments of apatite were observed in several concentrates but only in the Bridalveil granite do they reach the abundance of the euhedral crystals.

Zircon. Euhedral zircon occurs in every one of the specimens examined. For the most part the clear crystals show first and second order prisms and pyramids and ditetragonal pyramids. The larger crystals, which may reach dimensions of 0.1×0.2 mm. or more, are commonly crowded with minute unoriented prismatic inclusions. The zircons in the Sentinel granodiorite near Glacier Point, sg 3 and sg 4, are unusual in that they are rather ragged and broken and show a conspicuous development of the basal plane. Only in the Taft granite was it possible to recognize two equally abundant varieties of zircon—clear crystals similar to those in most of the other rocks and pale brown, rather stubby crystals, irregularly cracked but without inclusions. The brown, inclusion-free variety is lacking in the specimen from McGee Lake. This rock, mapped as Taft granite by Calkins, is not visibly connected with the areas of Taft granite near Yosemite Valley.

Allanite. Several of the more siliceous rocks contain a little allanite. Its presence in the El Capitan and Bridalveil granites was noted by Calkins. Reis⁶ has recorded the occurrence of allanite in pegmatite veins in blocks at the foot of Eagle Peak.

LOCAL CONCENTRATIONS

The occurrence of swirls or dark streaks together with large orthoclase phenocrysts containing zones of ferromagnesian minerals in the Cathedral Peak granite along the Tuolumne River offered opportunity for a detailed study of the distribution of heavy minerals in different phases of the granite. In Table 2 are given data on the heavy minerals in the normal granite, in a swirl, and in the orthoclase phenocrysts. The method

⁶ Reis, H., Note on the occurrence of allanite in the Yosemite Valley, California: *Science*, N.S., vol. 11, pp. 229–230. 1900.

of presentation is intentionally different from that of Table 1 since these closely related rocks can thus be treated to better advantage. The ratios give the proportions of the grains found in the counts.

TABLE 2. HEAVY MINERALS IN SWIRL AND IN PHENOCRYSTS OF CATHEDRAL PEAK GRANITE, ALONG TUOLUMNE RIVER NEAR MOUTH OF DINGLEY CREEK

	Index figure	Weight percentage of heavy separate				Grain count ratios		
		magnetite	biotite	hornblende	sphene	apatite sphene	zircon sphene	apatite zircon
Granite	5.3	22.6	45.2	17.0	11.3	0.2	0.02	10
Swirl	48.5	42.8	37.1	10.9	9.1	0.2	0.05	4
Phenocrysts	2.0	45.0	27.5	15.0	10.0	0.14	0.02	7

TABLE 3. HEAVY MINERALS IN DARK PHASES OF THE HALF DOME QUARTZ MONZONITE

	Index figure	Weight percentage of heavy separate				Grain count ratios		
		magnetite	biotite	hornblende	sphene	apatite sphene	zircon sphene	apatite zircon
Polly Dome								
quartz monzonite	10.9	19.2	45.0	24.8	10.0	0.22	0.025	9
swirl	38.0	11.3	61.8	21.8	4.7	0.15	0.03	5
Merced Lake								
quartz monzonite	12.0	16.7	54.1	20.8	6.7	0.3	0.03	10
autolith	31.4	11.2	56.1	28.0	3.5	1.0	0.1	10

The weight percentages of biotite, hornblende, and sphene include apatite, epidote, and zircon, respectively. In each case the mineral listed in the table is far the more abundant, and the figure can be taken to apply to this constituent alone. Taking into account densities and average grain sizes approximate corrections can be obtained from the grain count ratios. The corrections are very small. Epidote was found in small amount in all three concentrates, whereas zoisite was not recorded. A single grain of rutile was seen in the concentrate from the swirl.

The general character of the heavy concentrate varies little in spite of the wide variation of the index figure. The proportion of magnetite among the heavy constituents is greatly increased in both phenocrysts and swirl. Other changes are not striking, though the increase of the zircon/sphene ratio in the swirl may indicate the early entrapment of zircon.

Autoliths are not abundant in the Half Dome quartz monzonite and are found principally in the outer parts of the mass. Table 3, which is drawn up in the same fashion as Table 2, gives data on the heavy minerals in a swirl and in an autolith of this rock from two widely separated sources well within the mass. Data for the adjoining normal quartz monzonite are repeated from Table 1. The figures show clearly that the character of the concentration is similar in the swirl and in the autolith. The results are also very much like those given in Table 2, except that magnetite is not enriched in the dark phases.

PRESENTATION OF THE FIRST ROEBLING MEDAL
OF THE MINERALOGICAL SOCIETY OF
AMERICA TO CHARLES PALACHE

A. PRESENTATION—EDWARD H. KRAUS, *University of Michigan,
Ann Arbor, Michigan.*

This meeting marks another milestone in the development of the Mineralogical Society of America. Since its organization in the Mineralogical Laboratory of Harvard University on December 30, 1919, the Society has made steady and continuous progress. This is shown by the large growth in membership, by the marked increase in the number of articles published annually in *The American Mineralogist*, and by our very satisfactory financial assets.

Today the Society has one hundred and seventy-two fellows and more than four hundred members. There are also three hundred additional subscribers to *The American Mineralogist*, which is one of the leading publications in our field and is to be found in all important scientific libraries the world over. During the last ten years, *The American Mineralogist* has been materially improved and expanded, due in large measure to the generous gift of \$45,000 by the late Colonel Washington A. Roebling. The older members of the Society are well aware that the Roebling gift was an unconditional one, but that the donor expressed the hope that the income might be used to expand our journal. With much satisfaction we have followed its growth in size and importance since the receipt of the Roebling gift. We are especially proud of the current volume, which includes the impressive May number of four hundred and thirty-five pages, dedicated to Professor Charles Palache of Harvard University.

At the annual meeting in December 1929, the activities of the first ten years of the Society were reviewed, and the following statement was made:

It would be very helpful if the Society had the means to establish awards, either medals or money prizes, to be given to outstanding investigators in America or abroad, or to the authors of contributions adjudged as noteworthy. To be the recipient of a medal or prize of the Mineralogical Society of America would soon be recognized as a signal honor, one that would be greatly coveted.

To this suggestion there was a very favorable response. The council discussed the proposal and agreed that in recognition of the great stimulus given to our Society and to mineralogy in America by the Roebling gift, it would be eminently fitting to make provision for a medal in honor of Colonel Roebling. Accordingly, the Roebling Medal Fund was estab-

lished, and annually additions were to be made to it from the treasury until the amount would be sufficient to make the first award. Last December the council gave instructions that the medal should be designed so that it might be awarded for the first time at the 1937 meeting. The committee was extremely fortunate in securing as the designer of the medal the well-known artist and sculptor, Dr. Avard Fairbanks, who has given us a very appropriate and artistic medal.

Colonel Washington A. Roebling, in whose honor the medal is named, was born in Saxonburg, Pennsylvania, May 26, 1837. He was the son of John A. Roebling, a civil engineer, and graduate of the Technische Hochschule at Charlottenburg, Germany. Colonel Roebling, like his father, was trained for a career as an engineer. He attended the Rensselaer Polytechnic Institute, Troy, New York, from which he was graduated in 1857. He then joined his father in the construction of noted suspension bridges, such as those over the Niagara River at Niagara Falls, over the Allegheny River at Pittsburgh, over the Ohio River at Cincinnati, and the famous Brooklyn Bridge over the East River, New York. At the outbreak of the Civil War, he enlisted as a private. He was advanced steadily in rank, and at the close of the war, retired as Colonel. During the war he was in charge of the construction of several important suspension bridges.

While at work on the Brooklyn Bridge, he became ill, and was long confined to a darkened room. Although he first became interested in minerals while a student at the Rensselaer Polytechnic Institute, it was during the period of convalescence from this illness that his interest in minerals became intensified. It continued during the remainder of his life and resulted in an unusually excellent collection numbering about 16,000 specimens. Many of the newer and rarer minerals were represented by type material. Colonel Roebling freely permitted his specimens to be used for scientific purposes, and in this way he contributed directly to the publication of many important articles. As is well-known, following his death on July 21, 1926, his collection was presented to the National Museum in Washington.

Immediately after its organization, Colonel Roebling became identified with the Mineralogical Society of America, and in 1924 served as Vice-President. He followed the development of the Society with keen interest and was much concerned that it should grow in strength and influence. To assist in attaining these ends, he made his substantial gift to the Society shortly before his death.

Today, in making the first award of the Roebling Medal, we are again expressing our great appreciation of his significant contributions to American mineralogy and to the furtherance of the objectives of our

society. We also hope that through this and subsequent awards not only may the memory of Washington A. Roebling be kept alive, but that the medal may come to signify the highest recognition of achievement American mineralogy can bestow.

With enthusiasm the council voted last December that the first recipient of the Roebling Medal should be America's foremost mineralogist, and one of the stalwarts of the Society, whose publications during a period of forty years have covered a wide range of subjects and have contributed signally and enduringly to the advancement of our science.

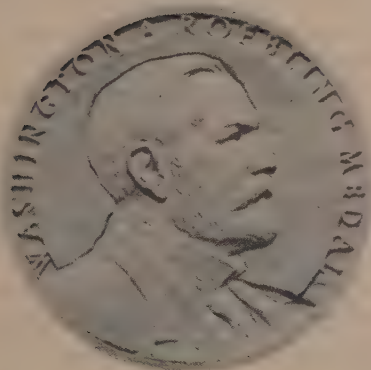
Charles Palache was born in San Francisco, California, sixty-eight years ago. He obtained his academic training at the University of California which he entered in 1887 as a student of mining. In 1891 he received the degree of Bachelor of Science. The next three years were spent in advanced study, and in 1894 he was awarded the degree of Doctor of Philosophy with petrography as the subject of specialization. During the period of graduate study, he served as a teaching fellow and assisted Professor A. C. Lawson in the conduct of the elementary course in mineralogy. After receiving the doctorate from the University of California, he attended the universities of Leipzig, Heidelberg, and Munich, where his abiding interest in crystallography and mineralogy was developed. In 1895 he was appointed to an assistantship in mineralogy at Harvard University, and the following year he was made instructor. In 1902 he was promoted to assistant professor, and in 1912 to professor of mineralogy. Moreover, since 1923 as chairman, he has had supervision of the instruction in mineralogy and petrography, and has also been curator of the Mineralogical Museum. In these various capacities he has served Harvard University most effectively for more than four decades. In addition, for eighteen years he was associated with the United States Geological Survey, as assistant geologist from 1901 to 1906, and as geologist from 1906 to 1919. As one of the editors, he is now actively participating in the preparation of the seventh edition of Dana's "System of Mineralogy."

Professor Palache's scientific contributions include about one hundred and twenty-five titles. In many of these papers the crystallography and paragenesis of minerals have been emphasized. He has described more than a dozen new minerals and several new meteorites. His various publications on the Goldschmidt two-circle method of crystal measurement have done much to introduce the method in this and other English-speaking countries. For more than thirty years, he has been an ardent student of the mineralogy of the zinc deposits of northern New Jersey, and at present is recognized as the foremost authority on the minerals of the famous Franklin Furnace District.

In recognition of Professor Palache's service to mineralogy, the large and impressive, special May number of *The American Mineralogist* containing thirty-five articles was dedicated to him by his friends and former students.

Professor Palache has been honored by many learned societies. He is a fellow of the Geological Societies of America and Belgium, of the American Academy of Arts and Sciences, and of the Mineralogical Society of America, of which he was president in 1921. He is also an honorary member of the Mineralogical Societies of Germany and Great Britain, a corresponding member of the Geological Society of Stockholm, and a member of the National Academy of Sciences. The fact that Professor Palache is now serving as president of the Geological Society of America clearly indicates his high standing as a mineralogist and geologist. It is also fitting to note that Professor Palache was for many years a close friend of Washington A. Roebling, to whom we do honor today for his unique service to American mineralogy by making the first award of the medal which bears his name.

CHARLES PALACHE: Inspiring teacher, enthusiastic collector and efficient curator of minerals, tireless investigator, distinguished contributor to the advancement of mineralogy, I have the honor, on behalf of the Mineralogical Society of America, to express the very high esteem in which you are held by the Society by presenting to you the first Roebling Medal.



OBSERVE



REVERSE

B. RESPONSE—PROFESSOR CHARLES PALACHE

As I accept from your hands this beautiful medal I find it hard to say whether pride or pleasure is my principal emotion. I may well be proud to receive this symbol of your approval of my life's work in my chosen science. Equally well may I take pleasure in the thought that the personal regard and friendship of many members of the Society goes with the award. I see among you colleagues of the present, fellow students of years gone by, pupils who have worked with me to enlarge our beloved science. I cannot assure myself that I am the one of all this fellowship who was rightly chosen to head the rôle of honor which will be constituted by the recipients of this medal through the years to come. But, since it is your will that my name should so head it, I thank you sincerely for the signal honor.

As I look upon the noble features of Colonel Roebling engraved upon this medal, my mind reverts to the delightful hours—all too few for my satisfaction—spent in his company. He always had a number of "tough nuts" for me to crack, generally some minute crystal from Franklin or Paterson, or some dealer's specimen whose label he doubted. His intense pleasure when I was able to confirm, at the time or through later tests, his own keen-eyed detection of some obscure specimen, was a rare delight.

From the very first time I saw his collection I realized the importance, not so much of his many rare and fine show specimens as of the drawers upon drawers of what he called his "Dana names," specimens for the most part of little beauty or distinction but representing authentic fragments of almost everything that had received a mineralogical name. Professor Phillips told in his memorial of Roebling how these specimens had been obtained and preserved. I had the temerity at our first meeting to tell him that whatever he did with the rest of his collection, these should go to some public museum, preferably the National Museum at Washington, so that this material, often unique, might be available in future years to all workers. Naturally, in saying this I take no credit for the ultimate gift of his whole collection to the National Museum. Still I may have sowed a seed in his mind.

Certainly I can take credit for influencing him unselfishly in another very different direction. I have in my file a copy of a letter that I wrote to Colonel Roebling in 1926. I had identified some minerals for him and had received in reply one of his charming notes written in his delicate, microscopic hand. The first Michigan and the first Harvard numbers of *The American Mineralogist* had then recently been published and I wrote to him thus:

I would be interested to know what you think of the plan which *The American Mineralogist* has adopted during the past year of publishing numbers of extra size financed by the aid of the institutions furnishing the material. Personally it seems to me an excellent plan. I look forward, however, to a time when the *Mineralogist* shall be sufficiently endowed to be able to publish such papers without the author or his institution having to bear the charges. I can think of no means of furthering the science of Mineralogy in this country more efficient than the establishment of a publication fund with an income sufficient to do this. I know that you have helped the Society and the *Mineralogist* in the past but would invite your earnest consideration of this suggestion for a movement to secure a permanent fund which should be ultimately not less than \$50,000.

Colonel Roebling did not reply to my letter but within a few days he transferred to the Treasurer of the Society bonds representing the large gift mentioned by Dean Kraus, which was accompanied by the following brief and characteristically modest note:

This gift is unconditional. I wish, however, that the whole, or part of it, be devoted to the publication of the monthly magazine, *The American Mineralogist*, which has been conducted on too narrow a margin.

Some weeks later he wrote me with evident satisfaction but quite as a postscript to a letter devoted to other matters:

I am simply overwhelmed by congratulations from dozens of mineralogists from all parts of the country, on account of my gift.

I cannot leave Colonel Roebling's memory without another quotation as a sample of the humor which cropped out in almost every letter he wrote. In the letter to which he appended the postscript just quoted, he acknowledged the receipt of the gift from me of a specimen of pumpellyite. He wrote:

In 1890 while living at Newport, R. I., the late Dr. Pumpelly had just returned from a trip to the glaciers of Montana. My wife gave him a reception at our house. He kindly gave us an entertaining narrative of his experience. My memory still retains an introductory sentence—"The roads were impassable, not even Jackassable."

Dean Kraus has related to you the academic stages of my life, but such a statement throws little light upon the personal influences which guided me.

To Joseph LaConte I owe surely my first insight into the meaning and beauty of geological science. To A. C. Lawson, who came to Berkeley just as I was completing my undergraduate course in Mining, I owe the inspiration that came from detailed work in the field. He saved me from a mining career that I hated in anticipation and through petrography set my course towards mineralogical science. When I went to Germany, I sat first under Zirkel, who at least taught me how *not to lecture*, for he read his lectures from proof copies of his newly written Petrography,

with which his hearers were also supplied. At Munich I worked chiefly with Groth, who lectured well but gave me such scanty help with goniometric work that at the end of a winter there I hated the very word crystal. At Heidelberg I heard Rosenbusch's delightful and instructive lectures in petrography, and he was charming also in the laboratory. But it was in the dark little room where Victor Goldschmidt met his few students that I found the guiding light to my future work. From the moment that I had measured a crystal on the first crude model of his two-circle goniometer and had projected it and had seen it in essence solve itself I knew that that was what I wanted to do all my life. And do it I have almost to the exclusion of all else of importance; and still the fascination of watching the picture of the crystal lattice appear as the angles are plotted holds me in thrall.

To the non-professional collectors whom I can claim as friends I owe much of the knowledge needful to the successful museum curator. Bement, Hancock, Fiss, Canfield, Roebling, Vaux, Holden, gathering minerals in large part for the aesthetic enjoyment of their form, color or natural setting, taught me how to evaluate rightly the qualities of a perfect exhibition specimen.

I do not think many men can have lived a happier life than mine has been. Going to Harvard with my newly kindled enthusiasm for crystallography still warm, Dr. Wolff made me free of all the resources of the mineralogical collections which had recently been entrusted to his care. He helped me to buy, borrow, or collect the crystals which I loved to describe. He it was who wisely counseled our friend, Albert F. Holden, in formulating his plans for generously endowing Mineralogy at Harvard so that it might thrive. When this gift was finally received in 1922, Wolff retired and placed in my hands the responsibility and delight of carrying out Holden's intent, and I soon found that where my plans for spending outstripped our now generous income I could turn to another Holden—Guerdon—who sits here among you today, with assurance that he would supply the wherewithal free from condition or proviso. To have visions and the material means for making many of them realities; to have students, many of whom stayed to become followers and then leaders on their own account; and to be able at all times to indulge my greatest interest of studying, measuring and comparing crystals—are not these abounding gifts which make for happiness?

Last spring, as Dean Kraus has stated, my friends and former students dedicated to me a series of papers which make a seemly volume in themselves. This surprise gift, for such it was, owing to the clever management of the editor, my good friend and former colleague, Martin Peacock, overwhelmed me with pleasure and deep emotion. Now you, fellow

members of the Mineralogical Society, once more overwhelm me with the honor of this medal. I should retire quickly from the scientific scene lest I reveal my inadequacy to deserve so many distinctions. But I cannot retreat yet. Dana's "System" must be newly issued in modern dress. We, the editors, must justify the faith the Geological Society has had in us by giving us the needful aid to carry this work through. Then I will retire with a grateful heart and leave it to new and better men to carry on the torch of progress in Mineralogy.

PROCEEDINGS OF SOCIETIES

NEW YORK MINERALOGICAL CLUB

With President B. T. Butler presiding, the meeting was called to order at 8:00 P.M. on Nov. 17, 1937, with 75 members and guests present. The completion of the incorporation proceedings was announced. Mr. L. N. Yedlin reported upon the club's trip to Strickland's Quarry on Nov. 7. Bertrandite in well-formed crystals was one of the rarer minerals found. A green hyalite, a new mineral for the locality, was also collected.

Following the business meeting, the Club was addressed by Dr. Frederick H. Pough upon "Scandinavian Mineral Localities" in which he gave an usually interesting talk upon his collecting trip of last summer. He illustrated the story of his travels with beautifully colored slides made from natural color photographs.

In Stockholm he was met by Mr. Albert Karlsson-Ygger, a member of the Club, now living there. He joined Dr. Pough on the first part of the trip, where his knowledge of the localities and the language were invaluable. Långban was first visited, where the mine was found in operation and a large number of interesting minerals found upon the dumps. It was discovered that the rarer minerals were no longer available. The most interesting find at this locality was of a green foliated mineral, perhaps related to pyroaurite, but which may be new.

Oslo was next visited and many unusual specimens seen in the Museum. Dr. Harald Bjørlykke was especially helpful with information on the pegmatite localities of Iveland and Kragerö, which were visited later. Many fine specimens from Norwegian localities were displayed including: very large feldspars, six inch thortveitites, magnificent fluorites and calcites from Kongsberg, and large pyroxenes from Nordmark, to mention only a few.

Iveland was the next stop and many of the quarries visited in the company of a guide, Olav Landsverk who had worked with Dr. Bjørlykke and who was familiar with the localities and minerals. As the quarries were widely scattered through the woods and swamps, the services of an expert were necessary to locate most of the openings. Replacement phenomena on a large scale was noted in three quarries where cleavelandite, microlite and other late minerals were involved. Rare earth minerals were abundant and their relations to the other minerals were shown clearly in many quarries. The new mineral scheteligite was collected and a few thortveitites were found at two localities. Monazite, euxenite, xenotime, fergusonite, and samarskite were abundantly present in many quarries.

Dr. Pough and Mr. Ygger then went to Kragerö, where they saw the famous pegmatites from which the phenakite has come, and where good specimens may still be found. A rutile mine and a little known but splendid sphene locality were also visited. Hellandite, betafite and orangite were among the rare minerals seen in Kragerö.

At Kongsberg they were well received and taken through the mine and workings. Native silver was found to be abundant, in wires and masses, and a nearby museum had a display of magnificent specimens.

Upon his return to Oslo, Dr. Pough joined Dr. Tom. Barth and Dr. Bjørlykke in a short trip to Raade, where in company with Dr. Tunell and Messrs. Marble and Henderson of Washington they visited an interesting pneumatolitic beryl occurrence.

Deviating from mineralogy for a time, Dr. Pough then went through the Norwegian fjords and took a North Cape trip, of which he had many pictures showing the mountains and sea. Upon the return from Narvik by rail the first stop was made at the famous Kiruna iron mines, where many interesting-looking specimens were seen in which some of the rarer phosphates were suspected. Kiruna has produced many minerals such as strengite, cacoxene, and eleanorite, but none of them are being saved today.

The same was found to be true at Malmberget, near Gellivare; where many interesting minerals were seen on the dumps, but now so badly weathered as to be worthless. Several mines are operating and good specimens should be obtainable if any interest in them were shown by collectors.

As a model mining community, the gold mines at Boliden were carefully inspected and the interesting zonal relationships seen. The change in the appearance of the orebody with depth was described, and in the lowest portion native gold was found in place as thin films on the rock. The appearance of complex sulphides in the lower levels accompanying pyrrhotite was hard to understand.

A neighboring deposit, operated by the same company, was one of the most interesting pegmatites seen on the whole trip. It is known as Varuträsk and has been the subject of much study by Prof. Quensel of Stockholm. This pegmatite was found to be practically identical with many of the complex American type of pegmatites, and specimens collected here could be placed side by side with similar specimens from Maine or Connecticut without showing any noticeable difference. Alломontite and its alteration product, arsenostibite, were quite abundant.

At Ytterby, near Stockholm, was another famous pegmatite visited. Here many of the rare earth minerals were found upon the old dumps demonstrating the sequence of crystallization, leaving little doubt of the primary nature of the crystallization.

At the close of the program, Mr. H. R. Lee read a copy of the proposed new constitution written to provide for the new status of the Club as an incorporated body. The meeting then adjourned for the inspection of specimens.

MARTIN L. EHLMANN, *Secretary pro tem*

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, October 7, 1937

A stated meeting was held with Mr. Arndt in the chair, and 27 members and 23 visitors present. The following officers were elected for 1937-1938: President: Harry W. Trudell, Vice-president: Morrell Baldwin; Secretary: Louis Moyd; Treasurer: Wylie Flack; Councillor: Harold Arndt.

Excursions were reported as follows: Miss Isabella Hellmer to Nova Scotia (chabazite, natrolite, analcite, heulandite, stilbite, gmelinite, apophyllite, and calcite); Louis Moyd to Canada (Madoc: fluorite and barite; Bancroft: sodalite, magnetite, nepheline, lepidomelane; Hybla: ellsworthite, cyrtolite; Lake Clear: augite, apatite, titanite); Leonard Morgan, with Albert Jehle to Adams and Cumberland Counties, Penna. (copper, piedmontite, wavellite, cacoxenite, quartz); Harry W. Trudell, William Knabe, and Samuel G. Gordon to Franklin County, Penna. and Frostburg, Maryland (piedmontite, siderite geodes containing barite); Mr. Gordon to North Carolina (corundum altered to margarite, garnet in mica, zoisite, monazite, zircon, smoky quartz, beryl, lazulite, pyrrhotite, pitchblende and uranophane, oligoclase, epidote); Nicola G. D'Ascenzo to Westfield, Mass. (epidote, datolite, prehnite, babingtonite); Dr. Gillson to New Mexico (fluorite); Edwin Roedder to Hellertown (wavellite); David Travis to Cornwall, Penna. (native copper); Louis Moyd to Beemerville, N. J., and Pine Island, N. Y., (nepheline, allanite, chondrodite, phlogopite, edenite); W. Hershey Thomas to Sparta Junction, N. J., (apatite). Mr. Raymond Collins described a western trip with John F. Lafferty in May and June. Caught in a blizzard in Wyoming, they were marooned for 6 days and lost their car. Their specimens were recovered.

W. H. FLACK, *Secretary*

Academy of Natural Sciences of Philadelphia, November 4, 1937

Mr. Trudell presided at a stated meeting with 43 members and 29 visitors present.

Mr. Charles R. Toothaker of the Philadelphia Commercial Museum spoke on "Collecting in Greenland," in which he described a visit to the cryolite mine at Ivigtut in September while serving as third officer on the cryolite boat (Norwegian) *Einvik*. Lantern slides and specimens of cryolite, chiolite, fluorite, hagemanite, thomsenolite, pachnolite, ralstonite, ivigtite, barite, and gearsutite were exhibited.

Mr. Albert Jehle reported on a trip with Messrs. Trudell, Knabe, and Gordon to Whitehall, Md., and to Pilot, Md. Mr. Morgan exhibited pearls he had collected from mussels in the Passaic River. Mr. Thompson reported stilbite and calcite from Perkiomenville, and malachite and aurichalcite from Bridgeport. Mr. Poole described briefly his visit to the museums in London.

LOUIS MOYD, *Secretary*

NEW MINERAL NAMES

Parkerite

DOUGLAS L. SCHOLTZ: The magmatic nickeliferous ore deposits of East Griqualand and Pondoland. *Trans. Geol. Soc. So. Africa*, vol. 39, pp. 186-189, 1937.

NAME: In honor of Professor R. Parker of Zurich.

CHEMICAL PROPERTIES: Perhaps nickel sulfide, either Ni_2S_3 or NiS_2 . Readily soluble with effervescence in HNO_3 .

CRYSTALLOGRAPHICAL PROPERTIES: Monoclinic. $b = 3.2\text{\AA}$.

PHYSICAL AND OPTICAL PROPERTIES: Soft, with luster like molybdenite.

Color, in polished section, creamy white with faint mauve tint. Strongly anisotropic and almost invariably shows multiple twin lamellae. Pleochroism distinct. Cleavage in three directions, yielding rhomboidal plates.

MINERALOGRAPHIC PROPERTIES: With HNO_3 , effervesces and stains brownish black, with HCl and HgCl_2 darkens; with FeCl_3 darkens instantly, developing cleavage and twin lamellae; aqua regia stains gray instantly; KOH and KCN negative.

OCCURRENCE: Associated with cubanite, sperrylite, galena, chalcopyrite, blende, pentlandite and several undetermined minerals

W. F. FOSHAG

Niggliite

DOUGLAS L. SCHOLTZ: The magmatic nickeliferous ore deposits of East Griqualand and Pondoland. *Trans. Geol. Soc. So. Africa*, vol. 39, pp. 184-186, 1937.

NAME: In honor of Professor P. Niggli of Zurich.

CHEMICAL PROPERTIES: Perhaps platinum telluride, PtTe_3 . Reacts for platinum (34.8%) and tellurium. Fuses at low red heat to yellowish metallic globule.

PHYSICAL AND OPTICAL PROPERTIES: Color silver white. Brittle, with no cleavage; soft.

Very high reflectivity, intensely pleochroic, pale blue to bright cream. Strongly anisotropic.

MINERALOGRAPHIC PROPERTIES: No reactions with HNO_3 , HCl , KOH , KCN , HgCl_2 or FeCl_3 . No reaction with cold aqua regia, but dissolves upon heating.

OCCURRENCE: Found in the concentrates from oxidized ore from dumps at Waterfall Gorge, Insizwa, associated with sperrylite, chalcopyrite, cubanite and several undetermined species.

W. F. F.